Living outside the city gates: a palaeopathological, demographic, isotopic and comparative analysis of the post-medieval St Gertrude Church cemetery population in Riga, Latvia

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Abstract

This research is based on 721 skeletons excavated from the complex site of the St Gertrude Church cemetery in Riga, Latvia, dating from the 15th - 17th centuries AD. The main aims of the analysis were to assess several aspects of physical health and diet of the local population and help to identify whether the people buried in two mass graves represent a different "population" group. To achieve these aims, both macroscopic and biogeochemical (isotopic) skeletal analyses were conducted.

The equal distribution of prevalence of dental disease suggest a similar diet in terms of the proportion of carbohydrates for the whole population. Adult dietary isotope analysis for 96 individuals does not reveal context-specific differences in values. Incremental dentine analysis for 19 children shows that non-adults in one of the mass graves experienced nutritional stress towards the end of their lives. Similar dietary profiles of some children from both mass graves suggest that they were members of the same community. Strontium isotope analysis for the same 19 children does not yield significantly different enamel ratios between the contexts and suggests that most children buried in the cemetery were likely from Riga. The analysis of evidence for compromised physical health shows that co-occurrence of cribra orbitalia and linear enamel hypoplasia may have predisposed children in the mass graves to higher frailty.

Comparison of St Gertrude's cemetery population and other contemporary Baltic cemetery populations shows no statistically significant differences in the prevalence of dental disease. Stature estimates show that men in high-status groups were significantly taller than those buried in St Gertrude's cemetery, while similar differences were not observed in women.

The scarcity of bioarchaeological research in Eastern Europe and the need for detailed and comparable data from the region makes this project an important contribution for future population health studies in this region and beyond.

Living outside the city gates: a palaeopathological, demographic, isotopic and comparative analysis of the post-medieval St Gertrude Church cemetery population in Riga, Latvia

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Chapter 1. Introduction

This research is based on the skeletons excavated from the complex site of the St Gertrude Church cemetery in Riga, Latvia, dating from the 15th - 17th centuries AD (Figure 1). This study analyses evidence for compromised physical health in this population and compares the data between the three main burial contexts: the main cemetery, and two mass graves, in which, according to historical accounts, poor rural immigrants might have been interred. Since in the post-medieval period the church was located outside the city walls, the analysis provides unique evidence for several aspects of physical health and diet of this suburban population, as expressed in prevalence of certain pathological conditions and dietary isotope values and helps to identify whether the people buried in the mass graves represent a different “population” group compared to that buried in the main cemetery with the help of strontium isotope analysis. To view the population in its regional context, previously published data on skeletal pathological lesions from contemporary urban and rural cemetery populations in the Baltic countries are compiled and used for comparative purposes. The resulting dataset aims to demonstrate whether there are significant differences in the physical health status between post-medieval urban and rural populations in the Baltic region and, if found, the reasons for disparities are explored. The scarcity of bioarchaeological research in Eastern Europe and the need for detailed and comparable data from the region makes this project an important contribution for future population studies in the region and beyond.

Figure 1. Showing Latvia, its location in Europe, and capital, Riga.

1.1 Historical Background

To understand the social status of the local population in Latvia, a brief historical background is necessary. Unlike in Western Europe, the prehistoric period in the territory of Latvia only came to an end in the late 12th century AD, when Christianity was introduced to the local Baltic ethnic groups along with dramatic changes in land ownership, as well as the social and political structure. During the 13th century, most local ethnic groups in the territory of Latvia were either voluntarily or forcefully converted to Christianity by German bishops and the Teutonic Order, as a result of their successful crusades in the region. As a consequence, the local population lost their political and economic independence. This process was first described in the chronicle written by Henry of Latvia (1180-1227: Chapters IV and V). From the 14th century onwards, Latvia experienced economic growth under feudal rule, and Riga became a major Eastern European trade centre. This included. exporting mainly linen and grain, and importing cloth, herring, wine and beer from German ports, salt from the Netherlands, and a wide variety of other goods, including sugar and peppercorns from European colonies from the 16th century onwards (Zeids, 1978: 146-49).

The 14th-17th centuries, when St Gertrude Church and cemetery were mostly in use, are characterised by long-term political instability in the Baltic region. The modern-day territories of Latvia, Estonia and Lithuania were divided between various political powers who dominated the region, including Sweden, the German Teutonic-Livonian Order, Russia, and the Polish-Lithuanian commonwealth. The borders changed several times following frequent warfare between them. Before the 16th century, Latvia and Estonia were a part of the Teutonic-Livonian Order, while Lithuania was an independent state, called the Grand Duchy of Lithuania. In 1569, the Grand Duchy became part of a new state, the Polish-Lithuanian Commonwealth (Stone, 2001: 62). The relationship between the Grand Duchy and the Teutonic Order was dominated by frequent warfare (Stone, 2001: 3). After the Livonian war (1558-83), Estonia and a part of Latvia, including the Vidzeme region, were also claimed by the Polish-Lithuanian Commonwealth, while the other part of Latvia became the Duchy of Courland and Semigallia (Šterns, 1997).

The 17th century in particular was characterized by several events which caused mass mortality of the populations of Riga and rural Vidzeme. At the beginning of the century, the outbreak of the Polish-Swedish war (1600-25) coincided with a year of poor harvests in the Vidzeme region. Raids of the invading Polish army in the region resulted in any remaining food sources being taken from the local subsistence farmers, causing hundreds of people to leave their homes and migrate to Riga for help. During the winter of 1601-2, these people stayed within the vicinity of St Gertrude Church and St George's hospital and, although the city did provide some food, many of the migrants died from cold and exhaustion, as well as other diseases (Napiersky, 1890). It is believed that most of the deceased were buried in St Gertrude's cemetery, which is also supported by the presence of archaeological finds such dress fittings characteristic of rural Vidzeme in the mass graves (Actiņš et al., 2009, Pīrangs, 1932, Rusovs, 1926). Shortly after the famine, a plague epidemic broke out in the region, thus likely causing more deaths, both in the migrant camp and in the city. Finally, another plague epidemic affected the same region in 1623 (Napiersky, 1890). The presence of two 17th century mass graves in St Gertrude's cemetery supports historical evidence for episodes of mass mortality during this period. However, the mass-mortality events affected the whole region, not only people from rural Vidzeme, and therefore the victims could also have been buried in single graves in the general cemetery, especially if they belonged to the local community. Moreover, while the cemetery was likely used as the final resting place for rural immigrants from Vidzeme, it also accommodated plague victims in Riga, who could not be buried inside the city due to lack of space (Pīrangs, 1932). Likewise, since the church was dedicated to travellers, the cemetery was also likely used for burials of those who perished on their journey and did not belong to any congregation in Riga. These possibilities will be explored in the following chapters.

St Gertrude Church was first mentioned in historical sources in 1413. It was built outside the old centre of Riga to accommodate the city's growing population, and to provide shelter for travellers. The church was named after Saint Gertrude of Nivelles, the patroness of travellers. For this reason, churches dedicated to St Gertrude were often built outside medieval cities as a shelter and the first calling point for people reaching the city. In medieval Riga, St Gertrude Church was built on the main route to/from the east, leading to rural Vidzeme, of which Riga is the capital, and further afield to and from Estonia and Russia (Pīrangs, 1932).

Gertrude village was located next to the church. Initially the population mostly comprised subsistence farmers, but as the suburbs around the city grew, craftsmen, servants and unskilled workers and their families also built their homes in the vicinity of the church (Figure 2). Likewise, there is evidence for several windmills in the area, which also likely provided work for the local people. Although most of the people living in and around Gertrude village were of a low social status, living near Riga might have improved their access to resources. For example, most Latvian subsistence farmers were the subjects of German landowners, who worked in their farms, with little spare time to tend their own fields and grow any surplus produce to sell in the markets (Dumpe, 1999: 119, Dunsdorfs, 1962: 183). Unlike their poorer rural counterparts, however, the farmers who lived in Gertrude village and elsewhere around Riga benefited from the proximity of this large trading centre and port, and access to its markets and other job opportunities (Zeids, 1978: 149). There is also evidence that the subsistence farmers of Riga and its suburbs had increased freedom from their landowners, compared to most farmers from rural areas, which was key for having more time to spend for activities designed to raise their own income (Dunsdorfs 1962: 253).

The suburban area around Gertrude village was mainly dominated by allotments, which belonged to the landlords of the inner city, and citizens of various social standing, including servants and the poor. Nearby was St George's hospital, on the other side of the road to Vidzeme (Figure 2). This has led historians to believe that St Gertrude was used by those staying and working at the hospital, and that the cemetery around the church might have been used for deceased patients (Šterns, 1998: 355).

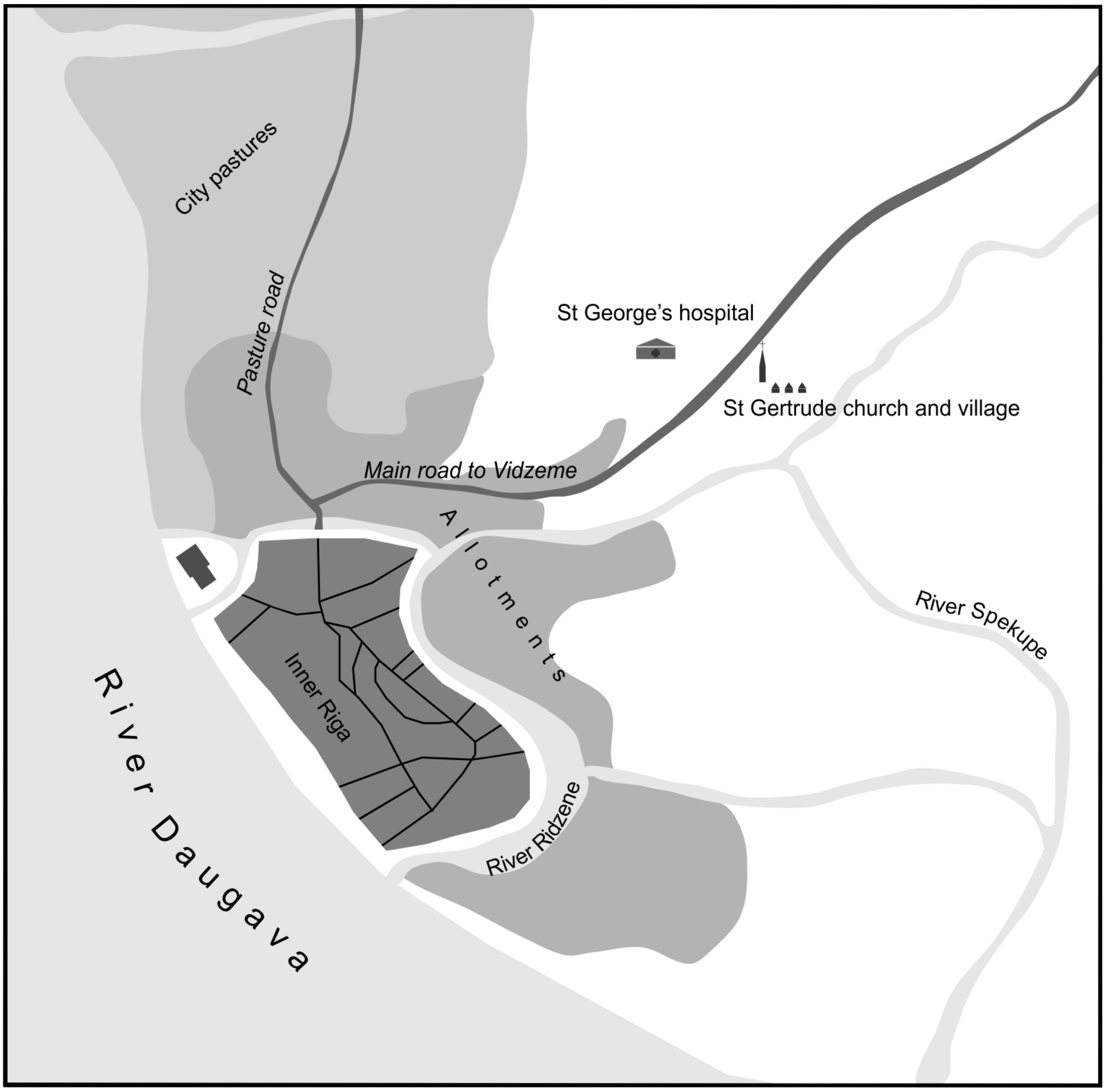

Figure 2. Map showing the location of St Gertrude church and village, and St George's hospital.

The living conditions of Gertrude villagers and the rest of the suburban population were less crowded than within the city walls, but the population was more vulnerable during warfare. The suburbs of Riga were built of wood to allow for easy destruction ahead of sieges; this was to remove the potential of shelter and resources for the invading army. During the 16th – 18th centuries, the suburbs were burnt down four times, in 1559, 1601, 1605, when the St Gertrude's Church was also destroyed, and 1710. The loss of property and resources in the fire of 1601 was estimated as equivalent to two barrels of gold (Jakovleva, 2009: 211).

1.2 Hypotheses, Research questions and Aims and Objectives of the research

Hypotheses, research questions and aims and objectives for this research were primarily focused on establishing if there were rural immigrants buried in St Gertrude's cemetery, as expressed in inter-contextual differences in prevalence rates of various pathological lesions, and values and ratios of carbon and nitrogen, and strontium isotope analyses, respectively. Based on historical sources, it was assumed that certain indicators of physical health would be different in the local St Gertrude's cemetery population, which had access to various resources due to Riga being a major trade centre, and remote rural populations, with more limited opportunities. To place St Gertrude's cemetery population in its regional context, prevalence rates of pathological lesions were contrasted with recorded data from other contemporary cemetery populations from Estonia and Lithuania. It was assumed that prevalence rates of certain pathological conditions would differ in urban and rural populations, as well as groups of higher and lower social status.

1.2.1 Hypotheses

1) Most individuals buried in the general cemetery were from the local area and thus represent an urban population with access to softer dietary carbohydrates, such as finely ground bread. This is predicted to be expressed in a higher prevalence of "destructive" dental diseases (caries, periodontal disease), lower dental attrition rates, and higher $\delta^{15}N$ values, indicative of more animal protein in their diet;

2) Most individuals buried in one, or both, mass graves represent poor rural immigrants. This is predicted to be expressed in a lower prevalence of destructive dental disease, higher dental attrition rates, and lower $\delta^{15}N$ values, indicating a diet dominated by plants;

3) Most individuals buried in one, or both, mass graves represent victims of plague, or another epidemic disease, who lived in Riga and/or its vicinity. This scenario is predicted to be expressed in similar prevalence rates of dental disease and $\delta^{13}C$ and $\delta^{15}N$ values, in line with people from the general cemetery.

4) Children from populations in Riga and nearby rural regions accessed available food resources differentially, especially marine and terrestrial protein, which would be expressed in detectable differences in incremental dentine profiles;

5) If the children in mass graves were rural immigrants who came to Riga during a famine, their diet as expressed in isotopic values is expected to have changed not long before death in most of these individuals, while any evidence of change should be more varied in children from the general cemetery.

6) Most individuals in the general cemetery were of local origin, while most of those in the mass graves were immigrants. This is expected to be expressed in significantly different $^{87}Sr/^{86}Sr$ ratios between the tested children in both mass graves and the general cemetery;

7) The prevalence of caries, periapical lesions and antemortem tooth loss in the St Gertrude's cemetery population will not be significantly different in people who lived in other urban and rural environments and were of a similar social status, but will be significantly higher in high-status groups, due to the availability of refined sugar;

8) The prevalence of linear enamel hypoplasia and cribra orbitalia will be higher in mass graves and rural population groups than in the general cemetery and other urban groups, as well as high-status populations;

9) Stature estimates for people from the general cemetery and the mass graves will be similar to those from other populations of low-moderate social status, but significantly lower than in high-status groups.

1.2.2 Research questions

The following research questions were proposed:

1. Are the frequent wars, famines and epidemics mentioned in historical sources reflected in the data on physical health and diet, and attained adult stature of the moderately wealthy St Gertrude's cemetery population?
2. How does the St Gertrude's cemetery population data compare to that from other contemporary urban and rural cemeteries in the Baltic region?

3. Were urban post-medieval populations in the Baltic region less affected by physical health problems, as reflected in their skeletal remains, than rural populations?
4. Do the individuals in the mass graves and the general cemetery represent different populations, based on evidence for physical health, diet, stature and strontium isotope ratios?

1.2.3 Aims and objectives of the research

The overall aims and objectives of the research were:

AIMS

- To analyse the remains of 721 individuals excavated from the St Gertrude's cemetery for evidence of disease (palaeopathology) in the form of dental disease, infectious diseases, and metabolic stress (enamel hypoplasia, cribra orbitalia and vitamin C and D deficiencies), in addition to their biological sex, age at death, and stature;
- To carry out radiocarbon dating from selected individuals in the cemetery;
- To carry out stable nitrogen and carbon isotope analyses on 30 individuals from the Mass graves (MGs) (15 from each) and 30 from the general cemetery (GC) for dietary analysis;
- To carry our strontium isotope analysis in eight individuals from the MGs (four from each) and four from the GC for migration analysis;
- To compare frequencies of pathological conditions between the individuals buried in the GC and the MGs, and to contrast these variables with other broadly contemporary urban and rural cemetery populations from Latvia;
- To compare rates of pathological lesions and stature estimates from the cemeteries in Latvia to those from urban and rural cemetery populations in the other two Baltic States (Lithuania and Estonia);
- To evaluate whether certain patterns emerge in the frequencies of pathological lesions in population groups living in the different Baltic States, in terms of their living environments (urban and rural), and differing social statuses;
- To study historical evidence relating to socio-cultural, economic and political factors which might have influenced the physical health of populations in the Baltic region in the 15th - 17th centuries.

OBJECTIVES

- Using the results of the palaeopathological and isotopic analyses of St Gertrude's cemetery population, to determine if the people buried in the MGs could have been rural immigrants;
- To obtain radiocarbon dates for the MGs in order to place them in a historical context and to aid interpretation;
- To understand how the political, cultural, economic and social environment influenced certain aspects of physical health of different population groups in the Baltic region during the 15th - 17th centuries.

1.3 Structure of the Thesis

This thesis is structured around five papers, each of which deal with the hypotheses, research questions, aims and objectives set out above. The following chapter (Chapter 2) gives a brief overview of palaeopathological lesions, demography, as well as adult stature, considered in this study. In order to place the St Gertrude's cemetery population in context, a brief historical background is also provided in this chapter.

Chapter 3 details the materials used, including data on comparative populations from Lithuania and Estonia, and all the osteological (sex and age at death estimation), palaeopathological, and biogeochemical (isotope analysis) methods applied to the skeletons during the research.

Chapters 4-8 are a series of papers on the different aspects of this research, and are co-authored by several people, who have contributed their expertise. Dr Guntis Gerhards and Prof Charlotte Roberts have co-authored all five papers; Guntis Gerhards helped with sourcing skeletal material, selection of all samples for biogeochemical analysis, as well as provided direction to historical sources for this thesis. Charlotte Roberts has commented extensively on each paper, and has provided meaningful advice on the methods, analysis, and interpretation of the osteological and palaeopathological analyses carried out during this research. All references for these papers are incorporated in the main References, at the end of this thesis (page 237).

Chapter 4 explores differences between people in the general cemetery and each mass grave in terms of dental attrition rates, as well as prevalence rates for dental diseases, and dietary carbon and nitrogen isotope values, with the main aim to observe if different population groups are present in each context. This chapter (Manuscript 1) is co-authored by Drs Janet Montgomery and Andrew Millard, who provided full guidance and advice on dietary isotope analysis from adult bone samples, including sample preparation, data analysis and presentation, and the interpretation of the results.

Chapter 5 offers a detailed insight into the diet and physiological stress of 19 non-adult individuals from the general cemetery and both mass graves, employing a recently developed method: high-resolution incremental dentine analysis. For this analysis, carbon and nitrogen isotope values from dentine collagen extracted at 1mm increments from a single tooth from each child were used to create individual dietary profiles from the beginning of the tooth formation to the death of the child. This chapter (Manuscript 2) is also co-authored by Janet Montgomery and Andrew Millard, because they contributed their expertise throughout the whole process, from sample preparation, to interpretation of the results. Likewise, Darren Gröcke, from the Department of Earth Sciences, Durham University, is also included as an author, since he provided guidance on preparing the collagen samples for the measurement process, measured the samples, and contributed a paragraph about the measurement process.

Chapter 6 explores the potential of strontium isotope analysis to distinguish possible immigrants in the St Gertrude's cemetery, using enamel from the same 19 teeth used in the incremental dentine analysis. The resulting data reflect the underlying geology, which influences the $^{87}Sr/^{86}Sr$ ratios in the soil, plants, animals, and eventually the humans living in the area; thus, if people come from two, or more geologically distinct areas, their $^{87}Sr/^{86}Sr$ ratios should differ. This chapter (Manuscript 3) is co-authored by Andrew Millard and Janet Montgomery, who offered extensive comments on data analysis and interpretation; Geoff Nowell, from the Department of Earth Sciences, Durham University, who oversaw sample preparation, measured the samples, and contributed a paragraph explaining the sample preparation, and the measurement process, and Jo Peterkin, who provided step-by-step guidance for sample preparation, assisted with the measurement process, and contributed towards the Methods section of the paper. Finally, Prof Vitālijs Zelčs from Faculty of Geography and Earth Sciences, University of Latvia is also included as an author, for providing meaningful information about the underlying geology of Latvia and contributing towards the relevant section in this manuscript.

Chapter 7 brings together all the data from Chapters 4-6, and deals with differences in prevalence rates of indicators of compromised childhood health (cribra orbitalia, linear enamel hypoplasia), vitamin C and D deficiencies, upper and lower respiratory infections, and indicators of non-specific health conditions (as expressed in periosteal new bone formation on long bones) between people buried in the general cemetery and mass graves, in order to compare particular aspects of their physical health, as well as frailty.

Chapter 8 places St Gertrude's cemetery population in a regional context and offers a comparative analysis of specific pathological lesions (dental disease, cribra orbitalia, linear enamel hypoplasia, and stature estimates) in contemporary populations from Latvia, Lithuania and Estonia. Apart from comparing and interpreting prevalence rates for the lesions, this chapter also highlights the importance of standardised methodology and reporting in the field of palaeopathology, in order to make data from cemetery populations from different regions comparable.

Finally, Chapter 9 provides an extended discussion about all the findings of this research, explains how the main aims have been met, and research questions answered, through each of the different analyses employed, and whether the hypotheses are supported, and draws conclusions for each aspect of the research, as well as its limitations, and future work.

1.4 Importance of the research

Studying the history of health in different regions of the world and in different time periods, with the help of standardised data collection, has become an important task of bioarchaeological research (Steckel et al., in press, Steckel et al., 2009). Bioarchaeology provides direct evidence about the lives of past populations, including compromised physical health and diet, and highlights differences between different sex, age and social status groups. In Eastern Europe, however, there is traditional separation of the disciplines of archaeology and bioarchaeology, and detailed mortality and morbidity studies of human skeletal remains are scarce. This has resulted in a considerable gap in knowledge about past populations in the region, and an urgent need for new studies (Jankauskas and Gerhards, 2012). Advances in scientific methods in archaeology have provided opportunities for studying prehistoric Latvian populations, which are unique due to their exceptional preservation and the abundance of archaeological evidence, including human remains. Working with international laboratories and research centres, bioarchaeological researchers have focused on the migration and dietary patterns of these populations, as well as solving complex issues related to the reservoir effect in radiocarbon dating (e.g. Larsson et al., 2017, Meadows et al., 2015, Oinonen et al., 2013, Stutz and Larsson, 2016, Stutz et al., 2013, Webb et al., 2015). This has placed Latvian ancient populations firmly within a European context by generating an abundance of accurate, comparable data and enabling comparative studies with other prehistoric population groups in Europe. However, Latvian cemetery populations of more recent date have not been subject to the same level of interest. Moreover, few detailed bioarchaeological studies have been carried out and published on any cemetery populations from Latvia, resulting in a lack of comparative data available to researchers in the region and elsewhere in Europe. This is because in Latvia, bioarchaeology is underrepresented as a science; no formal training in human osteoarchaeology, palaeopathology, or related disciplines, is available, and archaeology is only incorporated as a module in History programmes, thus limiting understanding the potential of the vast amount of information that it is possible to explore through such research. In the past, studies on Latvian cemetery populations have mainly focused on their biological affinities (Denisova et al., 1998, Zariņa, 2000), palaeodemography and life expectancy (Zariņa, 2003), as well as stature and physical development (Gerhards, 2003, 2005a). The few studies that include bioarchaeological and palaeopathological data are almost always published in local media (e.g. Gerhards, 2005b, 2006, Gerhards, 2009b, Zariņa, 2008), making the information inaccessible to wider audiences. This project will improve the situation in several ways:

- generate a comparable dataset from a unique skeletal sample;
- promote a new, comparative approach for population studies in the region by providing the first comparison of evidence for physical health in post-medieval Baltic cemetery populations;
- produce a number of publications in internationally recognised academic journals such as the *American Journal of Physical Anthropology*, the *International Journal of Paleopathology* and the *International Journal of Osteoarchaeology*, in addition to making presentations at conferences such as those run by the BABAO (British Association for Biological Anthropology and Osteoarchaeology) and the PPA (Palaeopathology Association);
- promote an interdisciplinary approach to bioarchaeological studies in Latvia, involving the related fields of history, anthropology, geology and chemistry in order to reconstruct a fuller picture of life and several aspects of physical health in the St Gertrude's cemetery population.

Moreover, the discovery of the mass graves in the cemetery has greatly added to the importance of the site in Latvian as well as European archaeology. Post-medieval mass graves in Europe that are not the consequence of warfare, are extremely rare: similar contexts have so far only been reported in France (Signoli et al., 2002) and in England (Bruce and McIntyre, 2009, McIntyre and Bruce, 2010). A detailed report from the St Gertrude’s cemetery mass graves resulting from this study will provide valuable comparative data and help to improve our understanding of how people dealt with disasters that caused catastrophically high mortality rates in the past.

Chapter 2. Demographic and palaeopathological analysis, adult stature, and isotope analysis

Demographic analysis of St Gertrude's cemetery population was carried out in order to understand the population structure (distribution of age and sex groups) and how it differs between the three contexts. Demographic analysis in archaeological populations will be described in section 2.1 below. All pathological lesions considered in this study were included according to their potential of revealing different aspects of physical health in a past population. Each of them will be briefly described below in section 2.1, in order to explain how their prevalence rates might be interpreted, while adult stature is discussed in section 2.2. To place St Gertrude's cemetery population in context, historical background is also given below in section 2.3. A brief background to isotopic analyses carried out during this research is given in Chapters 4 (adult dietary isotope analysis), 5 (incremental dentine analysis on 19 children's teeth) and 6 (strontium isotope analysis). All figures in this chapter, and in the rest of the thesis, have been created by the author.

2.1 Demographic analysis

Demographic analysis in archaeological populations aims to reconstruct the characteristics of the living population, mainly its size and structure (distribution of age and sex groups), but also its growth/decline over time, fertility, and mortality (Chamberlain, 2009, Chamberlain, 2006: 2). In the absence or scarcity of human remains, demographic analyses rely on radiocarbon databases, as well as large archaeological datasets, such as settlement sizes and artefact assemblages, and employ computer modelling to obtain information about ecological, economic, social, and political processes in prehistoric communities (Fitzhugh et al., 2016, Kohler et al., 2012, Kohler et al., 2005, Ritchie et al., 2016). Where skeletal remains are available for analysis, it is possible to model mortality patterns of the population with Bayesian and maximum-likelihood procedures, using the distribution of age and sex groups in the cemetery population as the basis (Chamberlain, 2009). More simple analyses, such as reconstruction of a demographic profile (by age and sex groups) for a cemetery population have the potential to identify events of catastrophic mortality and reveal information about which age/sex groups were prone to higher mortality, compared to others. Interpretation of normal versus abnormal distribution of age groups in an archaeological demographic profile is largely based on demographic profiles of recent historical populations, which were characterised by a high risk of mortality in early childhood, and very low risk in early adolescence, climbing steadily as the age progressed (Paine, 2000). This pattern of mortality has been proven to show regularity across many recent historical and living populations globally (Coale and Demeny, 1966, 1983). Conversely, a catastrophic mortality profile will be expressed in high mortality for all demographic groups (Keckler, 1997).

Demographic analyses which are based on archaeological populations are mainly biased by the difficulty of assigning accurate age estimates in skeletal remains. In non-adult skeletons, age can be estimated with considerable accuracy, especially where the development of teeth can be observed, as this process has been proven to be constant regardless of extrinsic factors (Demirjian et al., 1973, Moorrees et al., 1963). The level of accuracy decreases where the preservation is poor, and where skeletal elements are not observable at all. In adults, apart from preservation bias of the skeletal elements which can provide more accurate age estimates, and pubic symphysis and auricular surface of the pelvis in particular (Brooks and Suchey, 1990, Buckberry and Chamberlain, 2002, Lovejoy et al., 1985), there is a degree of inaccuracy in all methods of adult age estimation; this is further complicated by intra- and inter-observer error (Chamberlain, 2009, Roberts, 2009: 132-34). As a result, unequal distribution of age groups can occur when reconstructing demographic profile, whereby there are too few older adults, and too many adults in the middle age group (Molleson et al., 1993). For studies which require relatively narrow adult and non-adult age groups, for example, to distinguish attritional and catastrophic mortality profiles, this problem can be overcome by applying Bayesian statistics (Gowland and Chamberlain, 2005). These biases will be considered when interpreting the demographic profile of the St Gertrude's cemetery population. While applying Bayesian statistics was outside the scope of this research, it will be considered for future potential, as a means of carrying out a more detailed demographic analysis of the population. The methods used for adult and non-adult age, and adult sex estimation in this population, are given in Chapter 3.

2.2. Palaeopathological background

2.2.1 Dental attrition

Dental attrition is not a disease per se, but it was recorded during this study, because its presence and extent in archaeological skeletal remains can point to the coarseness of the diet, as well as the amount of abrasive particles in the food (Figure 3) (Brothwell, 1981: 71).

This, in turn, can help distinguish poorer populations, which in post-medieval Latvia mainly relied on coarsely ground bread, with inclusions of straw and other plant material (Dumpe, 1999: 122-7), as opposed to finely ground and sieved bread flour used by wealthier people (Hueck, 1845). Likewise, some studies have shown a link between slight dental wear and high caries rates with increased wealth in archaeological populations (Keenleyside, 2008, Larsen, 2015: 76-7). In modern industrialised populations, dental attrition is low, due to considerably softer diet, resulting from more advanced food processing and removal of abrasive particles (Larsen 2015: 278). This contrasts to more advanced dental wear in archaeological populations, as well as living communities who are mostly relying on traditional subsistence strategies, including hunting and gathering (Clement and Hillson, 2012, Davies and Pedersen, 1955, McKee and Molnar, 1988).

Figure 3. Advanced attrition exposes dentine on the crowns of all present mandibular teeth in an adult male (30+ years old) from St Gertrude's cemetery (burial 68).

2.2.2 Dental caries

Dental caries is a gradual demineralisation of the hard tissues of the tooth (Larsen and Fiehn, 2017, Marsh et al., 2009: 106). It is caused by organic acids which form as dietary carbohydrates are fermented by bacteria in dental plaque (Hillson, 2005: 291, Larsen et al., 1991: 179, Selwitz et al., 2007, Zero et al., 2008: 338). Although a variety of bacteria are thought to cause caries, including *Streptococcus mutans* (Featherstone, 2000), long-term research has shown that it is the disruption of the balance of the microflora of the plaque, rather than the presence of specific bacteria, that is responsible for the development of carious lesions; this can be caused by various reasons, including increased amounts of fermentable carbohydrates in diet (Marsh et al., 2009: 116).

Caries is highly prevalent in industrialised populations, routinely affecting 60-90% of schoolchildren and most adults (World Health Organization, 2016b). It is believed to have increased considerably with the advance of sedentary lifestyle in the past, since this was consistent with eating an increased proportion of carbohydrates, such as farmed crops (Larsen, 1995, Larsen et al., 1991). The introduction of refined sugar from the European colonies to Europe in the post-medieval period caused rapid deterioration of dental health, compared to the previous period. Initially only the wealthy had access to sugar, but eventually it became more widely available for the whole population (Adler et al., 2013). This was also shown by high caries rates in a high-status 17th century population from Jelgava, Latvia, who were known to have access to refined sugar (Pētersone-Gordina and Gerhards, 2011). Consequently, significant differences in caries prevalence rates between post-medieval populations might point to differential proportions of carbohydrates in the diet, as well as access to refined sugar. A number of bioarchaeological studies have proved that older people and women are generally more likely to develop the lesions (Cucina and Tiesler, 2003, Keenleyside, 2008, Larsen, 2015: 73, Larsen et al., 1991, Lukacs, 1996, 2008, Palubeckaite et al., 2006, Saunders et al., 1997, Watson et al., 2010). While a higher prevalence in older individuals is to be expected, since the number of carious teeth will accumulate with increasing age, in women the process might be exacerbated by an increase of oestrogen levels in saliva during pregnancy (Lukacs and Largaespada, 2006: 547). Indeed, a recent clinical study showed increased levels of salivary *Streptococcus mutans* in pregnant women (Kamate et al., 2017).

Figure 4. Advanced caries affecting all three right molars, with only one root remaining of the first molar, in a 35-45 years old female from St Gertrude's cemetery (Burial 139).

Advanced caries is relatively easy to identify in skeletal remains, especially when recording macroscopically distinguishable lytic lesions, rather than discolorations which occur in the initial stages of the disease (Figure 4) (Hillson, 2001). Some caries lesions, particularly those occurring on the cement-enamel junction, can be confused with post-mortem damage also often occurring in this area (ibid.). Likewise, even in occlusal caries, the initiation site may lie deep in the fissures, and is only distinguishable by radiographic examination (Dowker et al., 2006). In such cases, particularly when microscopic and radiographic analyses are not possible, caries prevalence in skeletal populations can be over- or under-estimated, respectively. Counting the prevalence of caries in archaeological populations is further complicated by fragmentation of skeletal remains, as well as teeth lost ante- and post-mortem. To increase accuracy, various methods of recording and calculating caries prevalence have been developed (Lukacs, 1989a, Moore and Corbett, 1971, Whittaker et al., 1981).

2.2.3 Periapical lesions

Periapical lesions forming at the apices of teeth signal that the involved teeth are fully or partly non-vital (Dias et al., 2007, Ogden, 2008: 295). Such lesions are classified as granulomata, cysts, or abscesses; while granulomata and cysts form as a result of necrosis of the pulp, which does not become infected and thus remains enclosed in the alveolar bone, abscess forms when external bacteria and/or fungi enter the space of the necrotic pulp and cause build-up of pus (Nair, 2004, Robertson and Smith, 2009), which eventually drains from the bone through the point of least resistance, often forming a smooth-walled sinus on the buccal or lingual side of the alveolar bone (Hillson, 1996: 285); granuloma involves the root of one tooth, while cysts are larger, and are considered evidence for either several granulomas becoming confluent, or expansion of a single necrotic area over several years, due to build-up of fluid (Ogden, 2008: 293-7). These lesions can be hard to distinguish in archaeological human remains, especially where the alveolar bone has been damaged post-mortem (Hillson, 2008: 322-23).

Granulomata which do become infected, are most often induced by advanced caries, whereby the pulp cavity becomes exposed (Hillson, 1996: 284, 2008: 322, Sivapathasundharam, 2009: 490). Although obtaining accurate epidemiological data from living populations is difficult due to differences in recording, hospital admission data for acute dental infections suggest that dental abscesses remain a significant dental health problem (Robertson and Smith, 2009). Severe attrition also can expose the pulp cavity and eventually lead to infection (Hillson, 1996: 284). In this study, the observation of both caries and dental attrition will help to differentiate between the causes of periapical lesions. Periapical lesions, especially abscesses, are an important indicator of dental health in past populations, as the sinuses can remain visible in the alveolar bone even after the tooth has been lost (Figure 5). Prevalence of periapical lesions in archaeological populations is complicated by the difficulty in distinguishing between granulomata, cysts, and abscesses, as discussed above. The majority of these lesions might have been benign, and thus cannot be readily taken as evidence for poor dental health (Dias and Tayles, 1997).

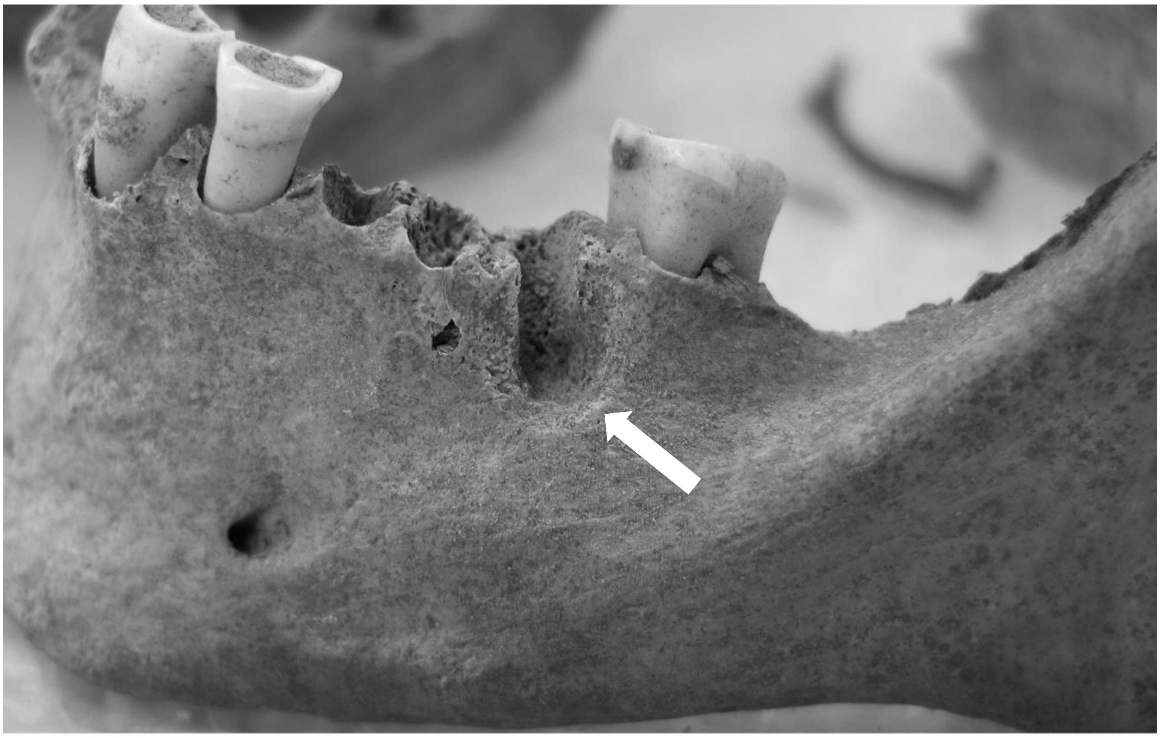

Figure 5. Left mandible with a periapical lesion affecting the M1, with the tooth absent, in a 35-45 years old male from St Gertrude’s cemetery (burial 293).

2.2.4 Periodontal disease

The main consequence of periodontal disease is a gradual loss of alveolar bone, which is most likely caused by advanced bacterial infection of the gingiva (the soft tissue surrounding the teeth) (Larsen, 2015: 78-9, Tonetti et al., 2015). This process can eventually lead to teeth being lost, and is the leading cause of ante-mortem tooth loss in living populations (Figure 6) (Marsh et al., 2009: 117). The disease in its severe form affects up to 20% of the global adult population (Gross et al., 2017, Jacob, 2012, World Health Organization, 2012), and it has a complex aetiology, with bacteria in dental plaque having a major impact on its development (Axelsson et al., 2004, Marsh et al., 2009: 117). In living populations, emotional stress, such as depression (Genco et al., 1998) and loss of a loved one (Hugoson et al., 2002) can be a significant factor in increasing the prevalence of periodontal disease. Likewise, there is a strong link between periodontal disease and general health, particularly with regard to cardiovascular and respiratory diseases (Leng et al., 2015, Marsh et al., 2009: 136). Since caries and periodontal disease are both associated with bacteria in dental plaque, the prevalence of both conditions is often similar in archaeological populations (Hillson, 2008: 321); this was also the case in the high-status Jelgava population, mentioned above with regard to high caries rates (Pētersone-Gordina and Gerhards, 2011). In this study, periodontal disease was viewed in relation to caries, as a potential indicator for the presence of carbohydrates in diet.

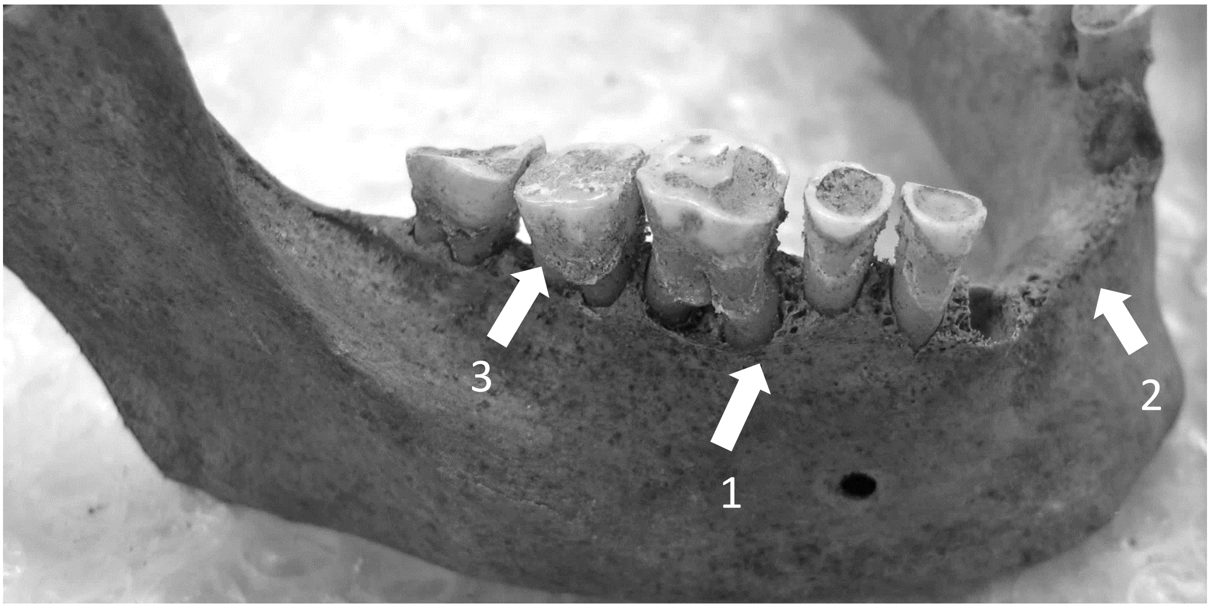

Figure 6. Periodontal disease (1) affecting alveolar bone around the right mandibular first molar and premolars, with the incisors lost antemortem (2), in an over 60 years old male from St Gertrude’s cemetery (burial 593). Slight-medium calculus deposits (3) are also present on the molars.

It has to be taken into account, however, that clinical evidence has proven a link between periodontal disease and general health, as discussed above. Likewise, studies on archaeological populations have found that individuals with periodontal disease and caries were subject to a higher risk of mortality (DeWitte and Bekvalac, 2010); and were more likely to have other pathological lesions signalling of compromised physical health, such as periosteal reactions (DeWitte and Bekvalac, 2011).

2.2.5 Antemortem tooth loss

In living populations, antemortem tooth loss (AMTL) is most often the consequence of plaque-related dental diseases mentioned above: caries and periodontal disease (Brennan et al., 2017, World Health Organization, 2012). It is estimated that around 30% of living adults aged between 65-74 years have no natural teeth left (World Health Organization, 2012, 2016d). In archaeological studies on historical populations, AMTL has been viewed in relation to differences in social status, with wealthier individuals often exhibiting better oral health and thus, lower rates of AMTL, compared to people of lower social status; these differences were explained by a higher proportion of protein and comparatively low amount of carbohydrates in the diet of high-status individuals, as opposed to poorer members of the society (Cucina and Tiesler, 2003, Frayer, 1984, Girotti and Doro-Garetto, 1999). The main aim of including AMTL in this study was to provide an approximate indicator of overall dental health, while the proportion of proteins in the diet of St Gertrude's cemetery population will be detected by dietary isotope analysis. Dietary isotope results will be considered when interpreting prevalence of all dental diseases, including AMTL.

2.2.6 Calculus

In living people, the tooth surface is covered by a biofilm of micro-organisms, or dental plaque (Marsh et al., 2009: 74-85, Selwitz et al., 2007). If not mechanically removed, plaque eventually mineralises, and becomes very difficult to remove during oral hygiene (Marsh et al., 2009: 96). Mineralised plaque, or calculus, deposits are present in over 80% of living people (ibid.). Calculus is also very common on the teeth of archaeological skeletons (Brothwell, 1981: 160), although its prevalence varies in different periods and geographic locations. For example, in Romano-British sites, 26.8% of people were affected, while the post-medieval, high-status Jelgava population yielded nearly 100% prevalence in adults (Pētersone-Gordina and Gerhards, 2011, Roberts and Cox, 2003: 132). The presence and extent of calculus can allow dental hygiene (or lack of it) to be explored in the past. Moreover, formation of plaque, and consequently calculus on the teeth, depends on various factors, such as individual oral microflora (Marsh et al., 2009: 96), and an inherited predisposition (Hillson, 2005: 289). Diet is also a factor in the development and composition of calculus; for example, a decrease in fibrous foods in the diet of agricultural populations might be linked to a build-up of plaque deposits, as shown by a considerably lower prevalence of plaque-related diseases in archaeological hunter-gatherer populations (Huynh et al., 2016). On the other hand, recent clinical studies have shown that considerable amounts of an amino-acid, L-arginine, which is naturally found in red meat, poultry and milk, effectively removes dental plaque (Kolderman et al., 2015, Tada et al., 2016). It is not currently known, however, if a diet rich in animal protein would also act against plaque bacteria developing. Obtaining more detailed analysis of ancient diet using calculus deposits is possible through microscopic analysis (Dudgeon and Tromp, 2014), but the deposits can also reveal information about specific diseases, by extracting bacterial DNA (Preus et al., 2011). Microscopic analysis was beyond the scope of the current research, but calculus, and its possible link to diet, will be explored by comparing the presence of deposits and $\delta^{15}N$ values, the latter of which are indicative of the proportion of animal protein in the diet. It will be taken into account, however, that calculus prevalence can be influenced by the loss of deposits in archaeological contexts, either due to taphonomic changes, or during excavation and/or curation of skeletal remains (Brothwell, 1981: 159).

2.2.7 Linear enamel hypoplasia

Enamel hypoplasia is representative of a short-term disruption of enamel formation, and therefore can only develop in childhood (DDE Index, 1982, 1992, Rajendran, 2009: 48). Although enamel defects can be inherited (Witkop, 1988), most often they are reported in children today who have experienced infections (Fiumara and Lessell, 1970, Pascoe and Seow, 1994, Stagno et al., 1982), metabolic disorders (Purvis et al., 1973), premature birth (Salanitri and Seow, 2013, Seow and Wan, 2000, Seow et al., 1987), or nutritional stress (Seow and Perham, 1989, Sweeney et al., 1971). Likewise, enamel hypoplasia tends to be more prevalent in individuals from lower status groups in living populations (Enwonwu, 1973, Goodman et al., 1987, Infante and Gillespie, 1974). For example, a high prevalence of enamel hypoplasia on the primary dentition was found in native Australian children who had experienced a combination of low birthweight, respiratory and gastrointestinal infections, and/or were born into families with a history of deprivation, especially with regard to the mother (Pascoe and Seow, 1994). There are several types of enamel hypoplasia, which have been described in more detail elsewhere (Hillson, 1996: 166-67, Ogden et al., 2007). Some types of enamel hypoplasia can be linked to specific pathological conditions, such as syphilis (Hillson et al., 1998, Jacobi et al., 1992), or tetany (Purvis et al., 1973). For this reason, it is advised to differentiate between the different types of hypoplastic defects when recording them in archaeological skeletons (Ogden et al., 2007). Furrow-type defects are the most common (Hillson, 1996: 166), and are referred to as linear enamel hypoplasia (LEH) in archaeological populations (Figure 7) (Goodman and Rose, 1990).

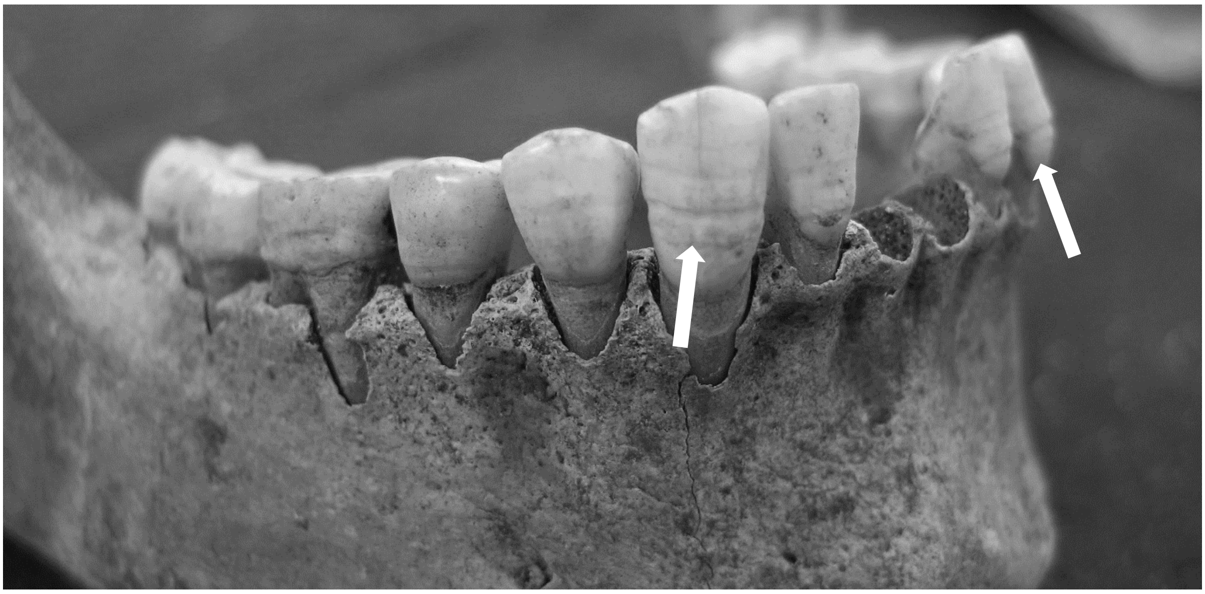

Figure 7. LEH in the form of multiple furrows affecting the mandibular teeth in a female aged 18-20 years, from St Gertrude's cemetery (burial 624).

Taking into account the clinical data about enamel hypoplasia in living people, in archaeological populations LEH is believed to represent arrested growth in childhood (Dobney and Goodman, 1991: 81, Goodman, 1991b, Goodman and Rose, 1991, Hillson, 1996: 165-6, King et al., 2005, Larsen, 2015: 44-5, Yaussy et al., 2016), and its prevalence might point to the general physical health of women and children, especially when analysed together with the presence of other pathological lesions indicative of compromised childhood health, and/or adult stature (Ogden et al., 2007, Vercellotti et al., 2014, Watts, 2013). Archaeological data is, however, limited by the variety of conditions causing disruptions in enamel formation, as described above; and by some teeth being unobservable due to ante- or post-mortem loss, heavy calculus deposits, advanced caries, or post-mortem damage to the tooth. These factors will be considered when interpreting LEH prevalence in the St Gertrude's cemetery population.

2.2.8 Cribra orbitalia

Cribra orbitalia (CO), or abnormal porosity of the orbital roof where the pores penetrate the lamellar bone surface, is commonly occurring in archaeological populations, and has been routinely recorded since it was first described by Welcker (1887) – (e.g. El‐Najjar et al., 1976, Mensforth, 1991, Mittler and van Gerven, 1994, Steckel et al., 2002, Walker et al., 2009, Zaino and Zaino, 1975) (Figure 8).

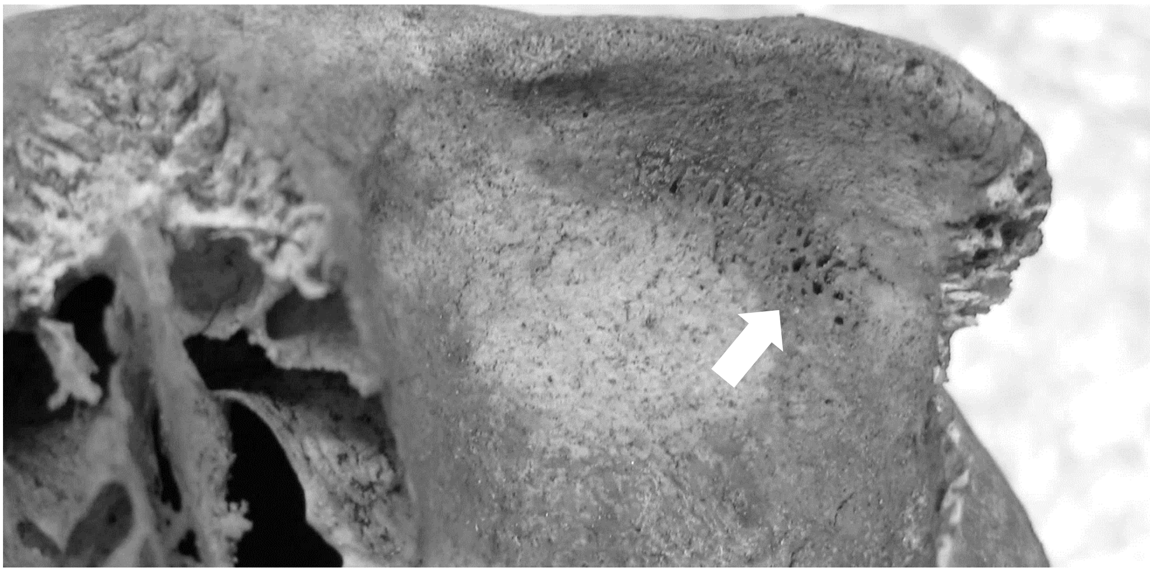

Figure 8. Cribra orbitalia in the left orbit of a 45-55 years old male from St Gertrude's cemetery.

Cribra orbitalia has been proven to be a condition that develops in childhood, because of the age-specific distribution of red marrow in the skull, the expansion of which is commonly linked to the lesions (see below); and the age-related characteristics of the periosteum, whereby it is not as firmly attached to the bone as in adults, allowing blood to enter into the subperiosteal space (Allen et al., 2004, Halvorsen and Bechensteen, 2002, Kent, 1986, Ma'luf et al., 2002, Stuart-Macadam, 1985, 1992, Tonna, 1974). Consequently, it was included in this study because of its potential to reveal evidence for compromised childhood health (Roberts and Manchester, 2010: 222-23, Walker et al., 2009).

The aetiology of the lesions, however, is still debated. Some research suggests that cribra orbitalia and similar porous lesions in the skull vault, porotic hyperostosis, might be related to anaemia - low concentrations of haemoglobin, or red blood cells (Stevens et al., 2013). In response the lesions develop as the red bone marrow in the skull vault expands, and the outer skull table thins; this leads to the production of new red blood cells to compensate for the destruction of old cells (Antony, 2013, Han et al., 2001: 6913). Nutritional, or acquired, anaemias are most often considered a cause in archaeological populations (Holland and O'Brien, 1997, Lanzkowsky, 1968, Mittler and van Gerven, 1994, Oxenham and Cavill, 2010, Ross and Logan, 1969, Stuart-Macadam, 1987a, 1987b, 1992), because they can be caused by a variety of factors, such as blood loss, poor nutrition, certain vitamin deficiencies and the body's response to infectious diseases and parasitic infections (Holland and O'Brien, 1997, Kent, 1986, McIlvaine, 2015, Oxenham and Cavill, 2010, Stuart-Macadam, 1991, 2006, Sullivan, 2005, Walker et al., 2009, Wapler et al., 2004). Populations in the past would likely have faced many of these life challenges, and the frequency of acquired anaemia may well have been high. According to World Health Organization data from a global survey, in 2011 anaemia was most prevalent in south Asia and central and west Africa and affected 29% (496 million) of non-pregnant women and 38% (32.4 million) of pregnant women aged 15–49 years (Stevens et al., 2013).

Genetic anaemias can result in similar, albeit more severe, skull lesions, although the post-cranial skeleton is also involved (Caffey, 1972: 1284, 1393, Diggs et al., 1937). Genetic anaemias are caused by abnormalities in haemoglobin synthesis (thalassemia - Daughety and DeLoughery, 2017, Piel and Weatherall, 2014; seen in people from the Mediterranean basin, the Middle East and Asia today – World Health Organization, 2006b), or the red blood cells themselves (sickle cell anaemia - Azar and Wong, 2017; seen in people from sub-Saharan Africa, India, Saudi Arabia and Mediterranean countries today – World Health Organization, 2006a). Likewise, severe malaria also can cause anaemia. Malaria is a disease caused by Plasmodium parasites transmitted to people through the bites of infected female Anopheles mosquitoes (Miller et al., 2002). Today, Malaria mostly affects African populations (90% of malaria cases globally in 2015), but the risk of infection is also present in South-East Asia, Latin America and the Middle East (World Health Organization, 2017). Although not prevalent in northern Europe, these types of anaemia are considered here for differential diagnosis, given that Riga was a major trade city in the post-medieval period, and the presence of people of various ancestries, or those who had travelled to malaria-endemic regions, in its cemeteries cannot be excluded.

Alternatively, porous lesions in the orbits can also represent other childhood conditions, particularly those involving bleeding into the subperiosteal space (see below); when healed, both, lesions caused by bone marrow expansion, and bleeding, have been reported to be almost identical (Brickley and Ives, 2006, Woo and Kim, 1997). Moreover, previous studies have shown a very weak correlation between thickening of the diploë of the skull vault and lesions in the orbits (Caffey, 1937, 1951, Hershkovitz et al., 1997, Sebes and Diggs, 1979, Stuart-Macadam, 1987a, 1987b, 1989); and microscopic studies have shown that not all skulls with orbital porosity also show marrow hyperplasia (Saint-Martin et al., 2015, Schultz, 2001). Accordingly, orbital porosity without any evidence of marrow hyperplasia in the skull or the post-cranial skeleton might have an entirely different aetiology, including subperiosteal inflammation caused by vitamin C and D deficiencies, as well as conditions causing subperiosteal haematomas, such as sinusitis complications, haemangiomas, and trauma

(Ma'luf et al., 2002, Sabet et al., 2001, Saint-Martin et al., 2015, Wapler et al., 2004, Woo and Kim, 1997).

Prevalence of cribra orbitalia in archaeological populations varies considerably, mainly due to small sample sizes , but also due to differences in recording; while the recording system proposed by Stuart-Macadam (1991: 109) is used most frequently, not all researchers include all five grades of severity of the lesions, or specify which grades are used, which can significantly affect the resulting prevalence (Lewis, 2017: 197). This will be taken into account when comparing prevalence of cribra orbitalia in St Gertrude’s cemetery population to other contemporary cemetery populations from the region. Apart from comparing and interpreting the prevalence of orbital lesions, some studies have included cribra orbitalia as a means of studying increased frailty in archaeological populations (DeWitte and Wood, 2008, Yaussy et al., 2016). This analysis will be applied to St Gertrude’s cemetery population, by means of comparing prevalence of cribra orbitalia, and other lesions indicative of compromised physical health, in people from mass graves and the general cemetery.

2.2.9 Maxillary sinusitis and rib lesions

Sinusitis, or inflammation of the paranasal sinuses, is a common condition today. Its acute form affects around 15% of the living population in western countries (Eloy et al., 2011). Most commonly, the condition is caused either by a viral infection, rhinitis (inflammation of the inside of the nose), or dental infection (Ah-See and Evans, 2007, Chapnik and Bach, 1976). While the acute form usually recedes within four weeks, and is therefore unlikely to leave any traces of its presence on the bones of the sinuses, the chronic form usually has a similar aetiology and is often a complication of the acute form (Ah-See and Evans, 2007, Boocock et al., 1995). The involvement of paranasal sinuses, resulting in sinusitis, is also common in lepromatous leprosy (Srinivasan et al., 1999). Before the mid-1990s, however, sinusitis had been studied in very few archaeological populations (Gregg and Gregg, 1987, Wells, 1977). Although usually not visible radiographically in clinical diagnosis, palaeopathological diagnosis is based on the assumption that chronic inflammation of the sinuses can cause the same type of bone reaction as elsewhere in the skeleton, and result in new bone formation and/or abnormal porosity (Figure 9, Boocock et al., 1995). In archaeological populations, sinusitis has been linked to crowded living conditions and/or high population density, whereby viral or bacterial infections causing sinusitis could spread easily by means of droplets containing the virus or bacteria expelled during coughing and sneezing

(Boocock et al., 1995, Lewis, 2017: 139). Alternatively, indoor and/or outdoor air pollution is also known to cause chronic respiratory disease in modern populations exposed to it (WHO, 2005, 2016a, 2016c), and therefore it has been considered when assessing the cause of sinusitis in the past populations (Merrett and Pfeiffer, 2000). One of the main factors limiting recording and analysing sinusitis in archaeological populations is poor preservation, or conversely, complete skulls in which sinuses are unobservable without an endoscope, the use of which often requires drilling a small hole in the maxilla (Lewis et al., 1995, Merrett and Pfeiffer, 2000, Wells, 1977). So far, sinusitis prevalence in archaeological populations has been varied, ranging from 30% to 50% (Boocock et al., 1995, DiGangi and Sirianni, 2017, Lew and Sirianni, 1997, Lewis et al., 1995, Merrett and Pfeiffer, 2000, Panhuysen et al., 1997).

Figure 9. Sinusitis, as expressed in new bone formation, in a right maxillary sinus of a 35-45 years old male from St Gertrude’s cemetery (burial 471).

Skeletal evidence for lower pulmonary infections, such as pneumonia and tuberculosis (TB) in skeletal remains is often limited to the visceral surfaces of ribs (Figure 10). In theory, if chronic infection from the lungs spreads via the pleura, ribs can become involved and develop reactive new bone. Such lesions have been reported in historical populations known to have died from lower respiratory infections (Eyler et al., 1996, Roberts et al., 1994, Santos and Roberts, 2001), and for this reason, analysis of ribs was also included in skeletal analysis of St Gertrude's cemetery population. In other recent, identified skeletal populations, new bone formation on the visceral surfaces of ribs has been found to affect the majority of people who had tuberculosis, ranging from 50% to 90%, while the lesions affected less than 20% of people who had other, non-TB pulmonary and extra-pulmonary conditions (Mariotti et al., 2015, Matos and Santos, 2006, Roberts et al., 1994, Santos and Roberts, 2001, 2006). Likewise, it has been suggested that the location of lesions on the ribs is also of importance when trying to distinguish different conditions causing them, with those that are TB-related, mostly affecting the neck area (ibid.). Other conditions which can cause rib lesions include sarcoidosis, lymphomas, tumours, and fungal infections (Hugosson et al., 1996). Despite extensive evidence in palaeopathological studies, care must be taken when interpreting rib lesions in archaeological populations, since they have not been confirmed in living TB patients due to difficult radiographic identification, or those who have died, due to autopsy strategies not requiring observation of visceral rib surfaces (Santos and Roberts, 2001). It has to be taken into account, however, that ribs are often fragmented in archaeological skeletal remains, thus compromising prevalence rates of the pathological lesions, and examination of their exact location, on these skeletal elements (Roberts et al., 1998). These factors will be considered when recording, and interpreting, the prevalence of rib lesions in St Gertrude's cemetery population.

Figure 10. New woven bone formation on the visceral surface of rib, located in the proximal 1/3 of the shaft, in an 8-9 years old child from a post-medieval cemetery in Turaida, Latvia.

2.2.10 Vitamin C and D deficiency

Vitamin C (ascorbic acid) is an essential nutrient for humans, and among its other roles in the body it helps to maintain intercellular connective tissues, osteoid, dentine, and collagen (Agarwal et al., 2015, Padayatty and Levine, 2001). Inadequate vitamin C intake over just 8-12 weeks can cause clinical symptoms, including irritability, fever, and loss of appetite (Algahtani et al., 2010, Solanki et al., 2011). Clinically, one of the main characteristics of scurvy is weakness of blood vessels. Initially, this results in bleeding and subsequent haemorrhagic skin lesions; if left untreated, larger blood vessels can become affected, thus causing bleeding at various sites inside the body. Joints, lower extremities, and the gingiva are affected most frequently (Hirschmann and Raugi, 1999, Olmedo et al., 2006, Shah and Sachdev, 2012, Touyz, 1997). Further progression of the disease can eventually result in weakening and fragility of bones, and subsequent fractures (Golriz et al., 2017, Gupta et al., 1989, Shah and Sachdev, 2012). Prolonged scurvy, whereby major blood vessels and bones are weakened, can cause rapid death (Altman, 1987, Hirschmann and Raugi, 1999). Because of inherent rapid growth and bone formation, bone involvement is more severely manifested in children, even in less advanced stages of the condition (Agarwal et al., 2015, Ortner, 2003: 284-6). In archaeological human remains of children, lesions possibly related to scurvy have been found in the skull, scapulae, ribs, and long bones of arms and legs (see Section 3.2.2 below).

In modern populations, scurvy has been reported in the elderly who live alone, people who experience psychological and eating disorders, or are addicted to drugs and/or alcohol (Bandini et al., 2010, Gongidi et al., 2013, Mintsoulis et al., 2016, Raynaud-Simon et al., 2010, Takeshima et al., 2014). Scurvy has also been reported in refugee populations, and also in developing countries due to seasonal shortage of fresh fruit and vegetables, and during humanitarian crises (Prinzo and De Benoist, 2002, Tchaou et al., 2016, Toole and Bhatia, 1992). Consequently, evidence for vitamin C deficiency in an archaeological population may suggest an inadequate diet, especially due to famine, war, or seasonal deficiency of fresh fruit and vegetables. It was therefore included in this study as an overall indicator of diet and access to resources in the St Gertrude’s cemetery population.

In other archaeological populations, evidence for scurvy has been linked to famine (Geber and Murphy, 2012), cultural practices related to weaning (Bourbou, 2014, Lewis, 2010), food shortages as a consequence of wars and earthquakes (Buckley, 2000), or work and/or travel in isolated areas, and consuming food with little or no vitamin C for extended periods of time

(Maat, 1982, 2004, van der Merwe et al., 2010). In children from archaeological populations, prevalence ranges widely, with the largest prevalence so far, 68% reported from a workhouse cemetery related to the Irish potato famine (Geber and Murphy, 2012). Thanks to excellent preservation, 80% prevalence was recorded in a group of 50 adult Dutch Whalers buried in Spitsbergen, Norway, during the 17th and 18th centuries (Maat, 1982, 2004), while only 14.9% of people from a gold mining community in Kimberley, South Africa, had lesions possibly caused by scurvy in their skeletal remains (van der Merwe et al., 2010). In most archaeological populations, however, prevalence of this disease in adults is very difficult to estimate due to more limited bone response in mature skeletons (Brickley and Ives, 2008: 61, van der Merwe et al., 2010).

In humans, the major natural source of vitamin D is from skin photosynthesis following ultraviolet (UV-B) solar irradiation (Hess, 1930: 107-17, Holick, 2008, Palaniswamy et al., 2017), although some foods are also high in vitamin D (see below). Consequently, inadequate exposure to sunlight for prolonged periods, especially in infants and children, can cause vitamin D deficiency (rickets in children, osteomalacia in adults) (Holick, 2006). The main role of vitamin D is to maintain adequate levels of serum calcium and phosphorus in the body which, in turn, are crucial for mineralisation of bone protein (osteoid), as well as for most metabolic functions (Bouillon, 2001, Holick, 1994, 2006, Mankin, 1974). When these functions are disrupted by a lack of vitamin D, one of the main consequences is poor bone mineralisation, which can result in weight-bearing bone deformities. Since bones grow and remodel rapidly in children, the deformities are much more common in this cohort (Huldschinsky, 1928, Pettifor, 2005). In adults, bone deformities in osteomalacia are similar to those occurring in a variety of other conditions, and are therefore more difficult to distinguish (Brickley and Ives, 2008: 125). More details on vitamin D deficiency-related bone changes in adults and children are given in Chapter 3 below.

Before understanding the role of sunshine in preventing the condition in the early 19th century, vitamin D deficiency had a very high prevalence in European cities, especially during and after industrialisation (Newman and Gowland, 2017). Often, the condition was exacerbated by inadequate diet, as foods like oily fish, and milk, are high in vitamin D, and can prevent deficiency (Holick, 2006, Merewood et al., 2010). In archaeological populations from the period, prevalence of rickets varies, with less than 8% of children affected in London (Lewis, 2002), 13% in Birmingham (Brickley and Ives, 2006), and over 30% in Beemster, Netherlands (Veselka et al., 2015). Osteomalacia is more difficult to identify, and prevalence of less than 5% has been reported from five post-medieval sites in England (Brickley et al., 2007, Roberts and Cox, 2003: 309).

Most frequently rickets has been reported in children between four and 18 months of age, before they are able to go outside on their own (Hollis and Wagner, 2004, Ortner, 2003: 393, Pettifor, 2003: 544). In westernised populations today, rickets is re-emerging, particularly in infants born to vitamin D deficient mothers, and/or during winter months (Holick, 2006, Merewood et al., 2010, Wharton and Bishop, 2003). Likewise, pregnant or lactating females have been proven to be most at risk of developing vitamin D deficiency, because of increased demands for calcium accumulation in the body (Prentice, 2003: 249). As with scurvy, elderly people are also at risk, when extensive clothing, or frailty, prevents adequate exposure to sunlight, and dietary intake is insufficient (Halloran and Portale, 1997, Wyskida et al., 2017).

2.2.11 Periosteal reactions on long bones

Periosteal reaction on bones, expressed as either healed (lamellar bone) or active (woven bone) lesions, can be indicative of a chronic, or a recent and/or ongoing, pathological condition, respectively. The presence of new bone formation on the long bones of the arms and legs, and particularly the tibiae is very common in archaeological skeletons (Larsen, 2015: 86-94, Ortner, 2003: 204-14, Weston, 2008). The lesions are thought to be the result of periosteal inflammation with a subsequent underlying bone reaction. It seems to occur in a variety of specific conditions, including scurvy, leprosy, TB, and treponemal disease, as well as trauma (Resnick and Niwayama, 1995: 4435, Roberts and Manchester, 2010: 172, Weston, 2008). Where periosteal reactions on long bones occur without any evidence for other changes in the skeleton which could be linked to a specific condition, they can be classed as non-specific, although care must be taken when recording incomplete skeletons, as affected skeletal elements essential for identification might be missing (Klaus, 2014, Weston, 2008). Earlier studies have found that periosteal reactions tend to be more prevalent in populations which, considering archaeological evidence, have been experiencing poor nutrition and subsequent vitamin deficiencies (Grauer, 1991, Katzenberg, 1992, Rose et al., 1991), while more recent research has suggested a link between active periosteal lesions (as expressed by the presence of woven bone) and a higher risk of early mortality (DeWitte and Wood, 2008).

2.2.12 Summary of demographic and palaeopathological analysis

To summarise, the demographic and palaeopathological analyses to be carried out during this research, while possessing a great potential for uncovering many aspects of life and death of St Gertrude's cemetery population, also include a number of limitations, which will have to be taken into account when interpreting the results. As mentioned above, these analyses are primarily biased by incomplete, or poor, survival of skeletal remains, which can skew the demographic profile, as well as limit the accuracy of prevalence rates of pathological conditions in the population. Furthermore, the limited response of mature skeletons to several pathological conditions, such as vitamin C and D deficiencies, and anaemia, will likely lead to underrepresentation of these conditions in the adult population. Finally, understanding the phenomenon of "osteological paradox" is crucial to this, and all other mortality and morbidity analyses in archaeological populations. It was first described by Wood et al. (1992), who cautioned against simplistic interpretations of pathological lesions in skeletal populations, whereby a higher prevalence was translated as an indicator of poorer physical health. Their main argument was that instead, three main factors characteristic to any living population, had to be considered: demographic non-stationarity, or the increase and decline of populations over time; selective mortality, which means that not all people with potentially life-threatening conditions will die from them; and heterogeneous frailty - a greater predisposition of particular age and/or sex groups, or individuals, to disease and consequently, premature death. Selective mortality and heterogeneous frailty are relevant when interpreting the absence of pathological lesions, whereby instead of being considered "physically healthy", these people might not have survived the episodes of illness and died before developing any lesions. Conversely, people with pathological lesions may actually represent physically healthier, or stronger, individuals, who could survive the conditions causing them (Ortner 1991). This is particularly true when interpreting lesions which formed over a longer period and had healed at the time of death – including cribra orbitalia and LEH, as well as deposits of lamellar bone. Since then, several studies have taken the argument further, and looked for different, more complex ways in which the results of palaeopathological analysis in past populations can be used and interpreted (Boldsen and Milner, 2012, DeWitte and Bekvalac, 2011, DeWitte and Hughes-Morey, 2012, DeWitte and Stojanowski, 2015, Klaus, 2014, Reitsema and McIlvaine, 2014, Sołtysiak, 2015, Temple and Goodman, 2014, Yaussy et al., 2016).

Moreover, health is a complex concept in living populations; The World Health Organization defines health as "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" (World Health Organization, 1948). Recent theoretical studies have also suggested that the term "health" is often misrepresented in bioarchaeological research, for it encompasses not only the absence of disease, but instead represents multi-dimensional, general well-being of a living person, which is impossible to measure in archaeological populations in its entirety (DeWitte and Stojanowski, 2015, McIlvaine and Reitsema, 2013, Reitsema and McIlvaine, 2014).

The prevalence of pathological lesions provides evidence for episodes of illness or skeletal trauma an individual experienced in the past, or was experiencing at the time of their death, but it does not provide a complete assessment of health for an individual or at a population level. This is further complicated by the fact that different people often experience different signs and symptoms of the same disease, and their response to the disease is also individual (Roberts, 2017). Some researchers therefore advise against using the term "health" to interpret absence or presence of certain pathological lesions (ibid; Temple and Goodman 2014). The lesions do, however, indicate disturbance in particular aspects of physical health, and therefore the term is used throughout this research, albeit only referring to physical health when interpreting results of the skeletal analysis.

For the reasons explained above, the demographic profile, and prevalence of pathological lesions will be interpreted with caution, taking into account the aspects of "osteological paradox", and considering differential diagnoses for each groups of pathological lesions/conditions, as well as avoiding misrepresentation of the term "health". Since prevalence rates can also vary due to differential recording or calculation methods, as demonstrated with regard to cribra orbitalia, care will be taken to describe the methodology employed in detail, to enable other researchers to use these data for comparative analyses.

2.3 Adult stature

A number of studies on historical and living populations have shown that stature can be influenced by social status and access to resources, with shorter statures associated with compromised living conditions, including poverty and systematic undernutrition. For example, it has been established that growth failure in the first 1000 days of life (beginning with conception) has a strong negative effect on the final adult stature (Stein et al., 2010, Victora et al., 2010). During pregnancy, the growth of the child is affected if the mother is undernourished. This, in turn, affects the child's adult stature, and birthweight of their future offspring (Victora et al., 2008). Likewise, inadequate nutrition and enteric infections in children are also clearly linked to stunted growth and reduced adult stature in developing countries (Alderman et al., 2006, De Onis and Blössner, 2003, Guerrant et al., 2008, Komlos, 1994). The link between compromised access to resources and shorter adult stature has also been demonstrated in historical populations (Carson, 2010). Data on living populations from developing countries suggest that an improvement in access to resources can trigger catch-up growth in young children, and reverse stunting; in older children, however, little or no catch-up growth was observed in similar conditions (Martorell et al., 1994).

The evidence for environmental influence on stature variation in living and historical populations has encouraged researchers to use stature estimates in archaeological populations as a proxy for general physical health status (Armelagos and van Gerven, 2003, Floud et al., 2011, Koepke and Baten, 2005, Steckel et al., 2002). Studies on adult stature and non-adult growth in the past support the modern data. For example, comparisons of contemporary archaeological populations from varying socioeconomic environments have found a positive correlation between access to protein sources and higher adult stature, and vice versa (Komlos, 1994, 1998). An earlier study of stature estimates in Latvian archaeological populations found the lowest statures in people from the poorest regions (Gerhards, 2005a). Likewise, the lowest femoral and tibial growth values in young children from the 18^{th}-19^{th} century London were consistent with low socio-economic status (Newman and Gowland, 2017). Accordingly, stature estimates in this study are used as an indicator of the overall physical health status of the population, in support of other data.

2.4 Isotope analysis

2.4.1 A brief overview of carbon and nitrogen isotope analysis

Carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope analyses of collagen were employed in this research in order to provide a more detailed insight into the diet of the people buried in the cemetery. While this method of analysis cannot detect carbohydrates unless protein consumption is extremely low and thus cannot directly support evidence for a high prevalence of destructive dental disease, it is a useful tool for detecting the proportion of animal ($\delta^{15}N$) and marine proteins in the diet ($\delta^{13}C$). Different $\delta^{13}C$ and $\delta^{15}N$ values might help to distinguish if:

- there were groups of people from different regions (closer and further from the coast),

- there was differential access to animal protein, and/or
- there were different diets for males and females

Moreover, certain animal (milk, cheese) and marine (fish) proteins have the potential to prevent dental decay (Zero et al., 2008: 334-5) and therefore the results of macroscopic and isotopic analyses are cross-compared.

Since the first use of carbon and nitrogen stable isotope analyses in relation to exploring diet in past populations (DeNiro and Epstein, 1978, 1981, van der Merwe and Vogel, 1978, Vogel and van der Merwe, 1977), they have become one of the most important means of studying dietary choices in the past (Ambrose, 1991, Ambrose et al., 2003, Katzenberg et al., 2012, Mays, 1997, 2010, Vanderklift and Ponsard, 2003, Wilhelmson, 2017). Isotope analysis is of particular importance in archaeology due to its potential to detect different food sources in the past and, most importantly, how these sources were used by different age, sex and status groups within the same population. In essence, $\delta^{13}C$ values reflect the presence of food chains based on plants with different photosynthetic pathways in the diet (C_3 and C_4 plants, which grow worldwide and mainly in tropical regions, respectively), as well as the contribution of marine resources (Harrison and Katzenberg, 2003). In Northern European studies, especially with regard to periods before the introduction of C_4 plants, $\delta^{13}C$ values are mainly used to study the proportion of marine resources in the diet (Mays, 1997, Pollard and Heron, 2008: 358). According to previous studies, a diet based entirely on marine resources will yield $\delta^{13}C$ values of around -12‰, while a C_3 diet with minimal or no marine input will result in $\delta^{13}C$ values around -21‰ (McGovern-Wilson and Quinn, 1996, Richards and Hedges, 1999, Schoeninger, 1989, Spielmann et al., 1990, Tauber, 1986).

The only source of nitrogen in the diet is protein (Chisholm et al., 1982, Hedges et al., 2004). $\delta^{15}N$ values reflect the trophic level of living organisms, and therefore they can be used to detect the proportion of animal protein as well as marine or freshwater resources in the human diet (Ambrose et al., 2003, Brown and Brown, 2011: 84). While it is not possible to accurately estimate the percentage of animal protein in the diet, a higher $\delta^{15}N$ value does indicate a higher proportion of meat or secondary animal proteins, such as milk (Ambrose et al., 2003, O'Connell and Hedges, 1999). Likewise, due to substantially higher $\delta^{15}N$ values in fish compared to terrestrial resources, the presence of marine or freshwater resources in a diet will also be expressed as higher $\delta^{15}N$ values in bone collagen samples (Katzenberg, 1989, 2008: 426).

Incremental dentine analysis to study seasonal variation in diet was first attempted on faunal remains (Balasse et al., 2001, Kirsanow et al., 2008), and later on human teeth (Fuller et al., 2003). The recent development of high-resolution dentine sampling, whereby much smaller dentine samples are necessary for obtaining sufficient amounts of collagen (Eerkens et al., 2011), has enabled analysing short-term changes in diet and/or dietary stress episodes, as demonstrated by Beaumont and co-workers in a study of the skeletons of probable Irish migrants to London during the Great Irish Famine (Beaumont et al., 2013). In essence, this analysis measures carbon and nitrogen isotope ratios in several consecutive dentinal increments from a single tooth, mapping yearly dietary changes, as well as possible stress episodes in an individual's life throughout the formation process of the tooth. Incremental dentine analysis is based on the fact that unlike bone, primary dentine does not remodel after it is formed (Nanci, 2003), thus retaining information about childhood diet and stress episodes throughout the individual's life; moreover, it grows at regular intervals every year (Dean and Scandrett, 1995), which allows for relatively precise sampling, and assigning chronological age for each increment (Beaumont and Montgomery, 2015). As a result, each increment provides an average of values for the period of its formation (Beaumont et al., 2013).

2.4.2 Strontium isotope analysis

Strontium (Sr) isotopes were first used to study mobility in past human populations in the mid-1980s (Ericson, 1985), and they have become one of the most effective methods to distinguish local and non-local individuals in early prehistory (Bentley et al., 2002, Cox and Sealy, 1997, Montgomery et al., 2000, Müller et al., 2003, Sillen et al., 1998) as well as later periods of history (Montgomery et al., 2005, Scheeres et al., 2013, Shaw et al., 2016). Sr is an alkaline earth metal with three non-radiogenic isotopes (^{84}Sr, ^{86}Sr and ^{88}Sr) and one radiogenic (^{87}Sr) isotope. Each type of rock has distinctly different $^{87}Sr/^{86}Sr$ ratios, which are released into soil and groundwater by the natural degradation process. From there, Sr isotopes pass largely unmodified through the food chain and into living organisms – plants, animals and humans (Graustein, 1989, Hurst and Davis, 1981, Kawasaki et al., 2002). Due to the similar chemical properties of Sr and calcium (Ca), when taken up by animals and humans with food and water, it substitutes for Ca in bone and enamel apatite (Bentley, 2006, Bentley et al., 2004), from where it can be extracted in archaeological faunal and human remains.

The $^{86}Sr/^{87}Sr$ ratios of underlying geological formations, however, cannot be used on their own to establish local biosphere values against which to compare the ratios obtained from archaeological human remains found in the same area. Despite the small rate of modification while passing from the rocks into the food chain, there are factors that also influence the isotope ratios in soil. For example, some minerals with high $^{86}Sr/^{87}Sr$ ratios also weather more slowly, which means that the isotope ratio in the soil is reduced compared to the whole rock (Åberg et al., 1989, Bentley, 2006). Likewise, Sr isotopes in coastal areas have been found to be dominated by seawater Sr rather than the underlying rocks, yielding $^{86}Sr/^{87}Sr$ ratios closer to that of the seawater, which is currently 0.7092 (McArthur et al., 2001). In the southern Baltic sea, the value can reach as high as 0.7097 (Price et al., 2012). This sea spray phenomenon has been described in studies from the Hawaiian Islands (Chadwick et al., 1999, Whipkey et al., 2000) and Guatemala (Hodell et al., 2004) in the Americas, and the Outer Hebrides in Scotland (Montgomery, 2006, Montgomery et al., 2003). A further complication is the decrease of $^{86}Sr/^{87}Sr$ ratios up the food chain. This means that $^{86}Sr/^{87}Sr$ variation in soil and plants is considerably reduced in animals, which eat a variety of plants in any area, thus averaging the $^{86}Sr/^{87}Sr$ in the skeletal tissue over time. Several studies have demonstrated a low standard deviation (SD) in $^{86}Sr/^{87}Sr$ in animal bones, including a comparison of ratios in soil, leaves, caterpillars, snails and birds (Blum et al., 2000), salmon (Koch et al., 1992) and elephants (Hall-Martin et al., 1993, van der Merwe et al., 1990). Consequently, obtaining $^{86}Sr/^{87}Sr$ ratios from the underlying rocks does not mean that they represent the locally available values for vegetation that grow in the soil, or those found in animals and humans who sourced food in the area.

To obtain $^{87}Sr/^{86}Sr$ ratios for mammals, which can be used to support human migration studies, researchers have compared isotope ratios from various modern and archaeological animal bones and teeth. Most studies have concluded that animals with a narrow roaming range, such as mice, rabbits, and squirrels have the lowest variation in $^{87}Sr/^{86}Sr$ and they therefore can provide a reliable estimate of local $^{87}Sr/^{86}Sr$ (Ezzo et al., 1997, Price et al., 2002).

It also has to be taken into account that archaeological bone is often subject to contamination and degradation during burial, so much so that the groundwater Sr can replace the existing Sr in the mineral portion of the bone (Hoppe et al., 2003, Lee–Thorp, 2002, Nelson et al., 1986). Likewise, dentine has also been proven to undergo diagenetic alteration in the burial environment, leading to considerable variations between enamel and dentine samples from the same individual (Budd et al., 2000).

The basement under the territory of Latvia is composed of Proterozoic magmatic and metamorphic rocks. The Ediacaran and Palaeozoic sedimentary rocks cover the surface of the crystalline basement, of which Devonian deposits form the uppermost part in almost the whole territory of Latvia (94%); these are generally found at a shallow depth, excluding areas of the eastern Latvian glacial uplands. In the south-west of the country, however, the Devonian rocks are replaced by Carboniferous, Permian, Triassic and Jurassic deposits in an area covering 3800km^2 (Zelčs and Nartišs, 2014; Lukševičs and Stinkulis, 2018, Figure 11). These sedimentary rocks only appear in restricted bedrock outcrop areas, such as in river valleys and coastal cliffs along the north-eastern coast of the Gulf of Riga; the rest of the bedrock surface is covered by the Middle and Upper Pleistocene, predominantly glacial, deposits of till, sand and gravel, and silt and clay, with an average depth of 5-20 m in the lowlands and 40-60 m in the uplands. In isolated areas of the highest local topography, particularly in the Vidzeme Upland, the Pleistocene deposits can reach a depth of up to 200 m (Zelcs et al., 2011). The sediments of previous interglacials have mostly been removed as a result successive glacial erosion of the Fennoscandian Ice Sheet, which covered the territory of Latvia four times (Dreimanis and Zelčs, 1995). Although no $^{87}Sr/^{86}Sr$ mapping has been done of Latvian bedrock or soils to date (Gilucis and Segliņš, 2003), it is expected that bioavailable $^{87}Sr/^{86}Sr$ ratios would depend on the composition of the Quaternary deposits, as is also the case in Denmark (Price et al., 2012). These form three main areas in the territory of Latvia, consistent with the direction of ice masses of the Baltic, Riga and Peipsijärv ice streams during the expansion and deglaciation of the last Fennoscandian ice sheet (Dreimanis and Zelčs, 1995). Despite the largely monolithic underlying geology, noticeable, if small, variations can be expected between these areas, although the ratios are expected to be dominated by Devonian deposits, which have yielded ratios of 0.7101 and 0.7121 in rocks (Evans et al., 2010) and 0.7113 and 1.7129 in vegetation in Britain (Chenery et al., 2010). The study site is located in the flat accumulative coastal plain of the Baltic Ice Lake, built-up of fine-grained to medium grained sand as a result of re-deposition of older glacial material between 13.7 and 11.7 ka cal BP. The plain surface has also been reworked by aeolian activity to some extent.

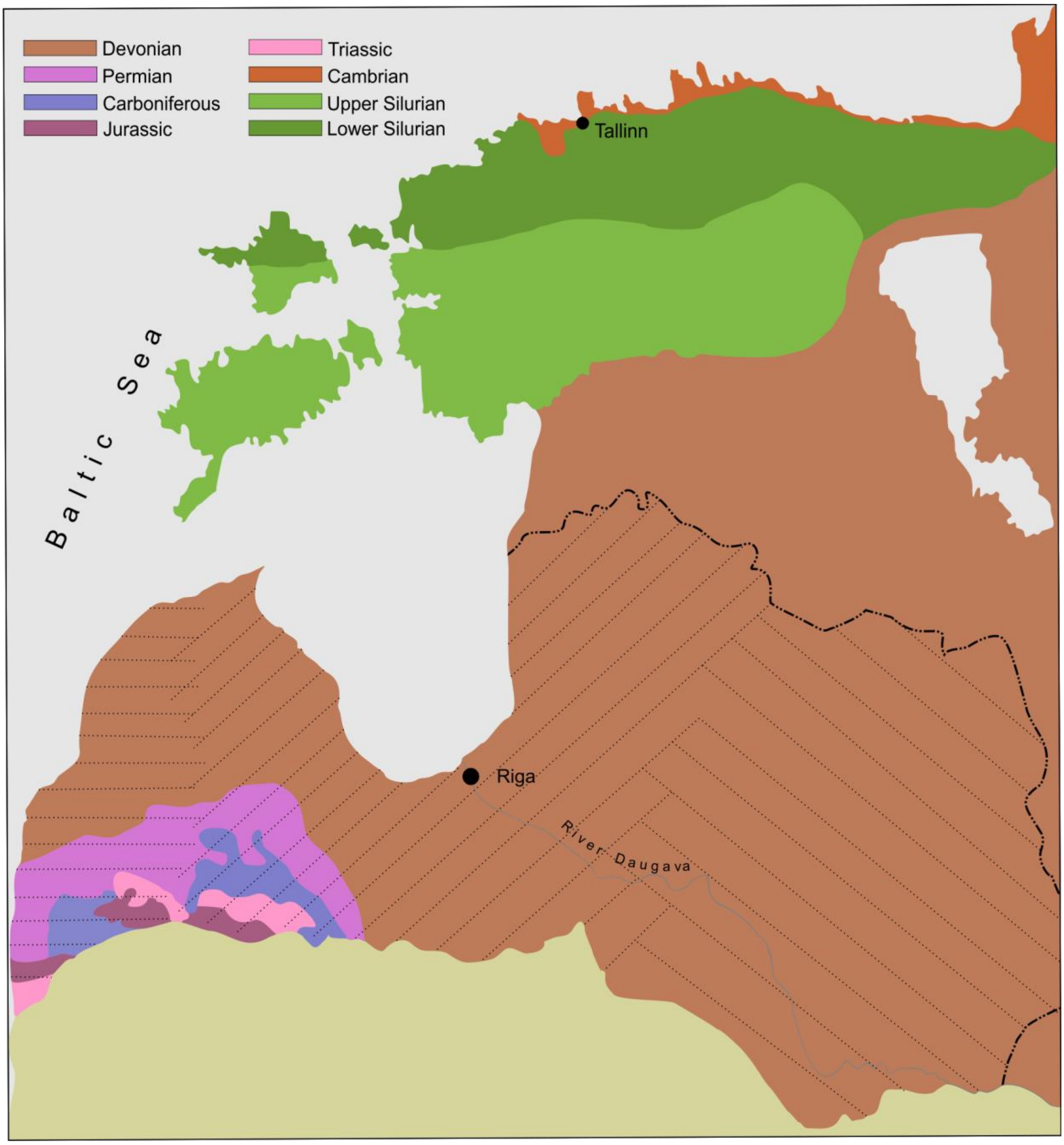

Figure 11. Geological map of Latvia, showing also Estonia. The dotted lines highlight approximate boundaries of the three main areas of quaternary deposits in the territory of Latvia (map combined from Brangulis et al., 1998, Danilans, 1973, Dreimanis, 1939).

Chapter 3. Materials and Methods

3.1 Materials

This study is based on 721 well-preserved, complete skeletal remains from the St Gertrude Church Cemetery in Riga, Latvia, circa late 15th – late 17th century AD. All individuals were excavated between August and October 2006 prior to planned building works. An area of 195m^2 was uncovered of the cemetery. Its original size is unknown, but archaeological evidence suggests that burials extended into all directions from the uncovered area (Actiņš et al., 2009: 59-60). Because the site is in the centre of the city, dense infrastructure prevents further analysis. During the period the church and cemetery were in use, they were located outside the old city wall.

Apart from recovering burials from the general cemetery, two mass graves were discovered in the south-eastern and north-western corners of the excavation area, containing 163 and 120 buried individuals, respectively (Figure 12); there was also a small collective burial pit, with 15 individuals. Unlike the general cemetery, the mass graves were almost completely excavated (ibid.). Significantly different rates of certain skeletal pathological conditions (mainly joint disease and trauma) between the individuals buried in the mass graves and the general cemetery were found in a preliminary analysis which, in conjunction with archaeological dating evidence from these three contexts, has allowed archaeologists to suggest that at least two, or even three different population groups were buried in this cemetery (Gerhards, 2009a).

Figure 12. Burials in the south-eastern mass grave (photo by Guntis Gerhards).

According to previously acquired data (ibid.), there were 435 individuals in the general cemetery (GC), including the burial pit, and 286 individuals in the mass graves. In the GC, there were 187 non-adults (0-17 years old), 115 males, 100 females and 18 adult individuals for whom sex could not be estimated due to poor preservation. In the south-eastern mass grave (MG1), there were 55 non-adults, 63 male and 48 female individuals, and in the north-western mass grave (MG2), there were 40 non-adults, 46 male and 34 female individuals. In the burial pit, there were three male, nine female, and three non-adult individuals. Because of the small sample size, individuals from the burial pit were studied together with people from the GC. Age and sex estimates for all individuals were re-assessed during skeletal analysis of the current research.

Certain aspects of physical health of the St Gertrude's cemetery population were also evaluated from a regional perspective. For the comparative analysis in the current research, data from 3659 individuals in 17 contemporary cemetery populations from Latvia, Lithuania and Estonia were compiled from previously published reports (Table 1).

Table 1. Available comparative post-medieval cemetery populations in Latvia, Lithuania and Estonia.

Cemetery	Status	Location (U/R)	Sample size	Reference
		Latvia		
Riga Dome Church	aristocracy	U	31	Gerhards, 2009b
Riga Dome Square	moderate	U	163	Gerhards, 2009b; Zariņa, 2008
RSPCC	low/moderate	U	118	Spirģis, 2012
Jelgava Holy Trinity Church cemetery	high	U	108	Pētersone-Gordina and Gerhards, 2011; Pētersone-Gordina et al., 2013
Saldus Church	aristocracy	U	13	Gerhards, 2000
Saldus general	low	U	16	Gerhards, 2000
Ventspils	moderate	U	103	Gerhards, 2005b
Valmiera	moderate	U	56	Zariņa, 2008
Madona	low	R	85	Gerhards, 2006
Cesvaine	low	R	46	Gerhards, 2006
Tērvete	low	R	21	Gerhards, 2000
Priedīši	low	R	19	Gerhards, 2000
		Lithuania		
Vilnius	aristocracy	U	71	Palubeckaitė et al., 2002
Vilnius	moderate	U	1500	Palubeckaité and Jankauskas, 2001
Subačiaus Str.	low	R	88	Palubeckaitė et al., 2002; Palubeckaité and Jankauskas, 2001
Alytus	moderate	U	1152	Jankauskas, 1995
		Estonia		
Pärnu	low	R	117	Allmäe and Limbo, 2010; Limbo, 2009
Tääksi	moderate	U	70	Allmäe, 1999, 2000
Kaberla	l/m	R	42	Heapost, 2003, Mark, 1962
St Barbara (Tallinn)	l/m	U	128	Allmäe, 1999, 2000, Heapost, 2003

U=urban, R=rural; RSPCC – Riga St Peters' Church cemetery

All cemetery reports contained information on dental disease, adult stature and cribra orbitalia. Most researchers had used standard recording methods for skeletal recording, which made the results comparable with the data collected during the skeletal analysis of the St Gertrude's cemetery population. The aim of the comparative study of contemporary urban and rural cemetery populations in Latvia was to determine whether specific patterns for the observed pathological lesions emerge in population groups from urban and rural living environments and of high and low social statuses. Although during the post-medieval period the Baltic States were controlled by different political powers, historical evidence suggests that the living conditions of subsistence farmers were similar (see Chapter 8) and thus a regional comparison was relevant. More detail on the methods used for each comparative population is given in Chapter 8.

3.2 Methods

The methods used for skeletal analysis were selected to address the research questions and to test the hypotheses outlined in Chapter 1. In addition, both basic osteological (age at death, sex, and metrical data) and palaeopathological methods were chosen with comparability, clarity and established standards for recording in mind. Osteological data were collected in order to create comparable demographic profiles for the different groups buried at St Gertrude's cemetery, to aid the analysis and interpretation of pathological conditions by age and sex groups, as well as to calculate stature estimates.

The pathological conditions for recording were chosen according to their potential for revealing information about particular aspects of physical health and diet in skeletal populations (Brickley et al., 2007, DeWitte and Hughes-Morey, 2012, DeWitte and Wood, 2008). Taking into account a number of previous studies, it was believed that the prevalence of dental diseases, as well as evidence for scurvy, anaemia, rickets/osteomalacia and pulmonary infection would best reflect living conditions in the St Gertrude's cemetery population and highlight possible differences between the individuals buried in the general cemetery and the mass graves, as well as differences between contemporary populations in the Baltics. The skeletal analysis included the skull, the pectoral and the pelvic girdles, as well as the long bones of the arms and legs. The hands, feet and the vertebral column were not included in the study. Although diseases such as vitamin C and D deficiency can affect these elements by causing osteopenia (Dent and Hodson, 1954, Joffe, 1961, Mankin, 1974, Reynolds and Karo, 1972), it is hard to detect without radiological analysis, which was not possible for this study.

3.2.1 Osteological methods

Sex and age at death for the St Gertrude's cemetery population were estimated using standard osteological methods, summarised in Tables 2 and 3, respectively. To estimate adult stature, regression equations developed on the basis of skeletal remains from Latvia were used (Gerhards, 2005a), based on the original stature estimation formulas for white males and females (Trotter and Gleser, 1952).

To estimate sex in adult individuals, assessment of the morphology of the pelvis and skull was used, with the former taking priority for sex estimation if both were preserved for observation. The methods are summarised in Table 2.

Table 2. Methods used for adult sex estimation.

Method	Reference
Preauricular sulcus of the pelvis	Milner 1992
Sexual dimorphism of the greater sciatic notch of the pelvis	Buikstra and Ubelaker 1994: 16-38
Sexual dimorphism of the subpubic region of the pelvis	Phenice 1969
Sexual dimorphism of cranium and mandible	Acsádi and Nemeskéri 1970

Table 3. Methods used for non-adult and adult age estimation.

Method	Reference
NON-ADULT	
Tooth formation and eruption	AlQahtani et al., 2010
Epiphyseal fusion of the long bones	Ogden et al., 1978, Schaefer, 2008
Long bone length	Fazekas and Kósa, 1978, Maresh, 1970
ADULT	
Degeneration of the pubic symphysis	Brooks and Suchey, 1990, Meindl et al., 1985
Degeneration of auricular surface	Buckberry and Chamberlain, 2002, Lovejoy et al., 1985
Degeneration of sternal rib ends	Işcan et al., 1984, 1985, Loth and Işcan, 1989
Cranial suture closure	Meindl and Lovejoy, 1985

For ageing non-adult individuals, mostly tooth formation and eruption stages were used, as well as long bone measurements. Where possible, the adult individuals were assigned ten-year age categories using either degenerative changes of the pubic symphysis or the auricular surface. Where this was not possible due to advanced joint disease or poor preservation, age estimates were based on cranial suture closure and degenerative changes of the sternal rib ends, and broader age categories were assigned as a result. The methods used for age estimation in adults and non-adults of the St Gertrude's cemetery population are summarised in Table 3.

3.2.2 Palaeopathological methods

Palaeopathological conditions were mostly recorded by presence or absence to enhance comparability with other contemporary populations, to avoid intra-observer error, especially with grading systems, and also to increase the observed number of individuals in the limited amount of time available for this research. The pathological conditions, as well as their possible interpretations are briefly summarised in Table 4.

Table 4. Pathological conditions included in the skeletal analysis and their potential interpretation.

Disease	**Possible interpretation**	**References**
	Dental disease	
Dental attrition, caries, periapical lesions, AMTL♦, calculus	Diet, oral hygiene, access to dental treatment	Hillson, 2001; Lukacs, 1989; Murphy, 1959; Ogden, 2008: 293-97; Smith, 1984
Periodontal disease	Diet, oral hygiene, evidence of scurvy	Ogden, 2008: 292-3
Enamel hypoplasia	Hardships during early childhood	Buikstra and Ubelaker, 1994: 56-7; Ogden, 2008: 284-88; Roberts and Connell, 2004
	Other conditions	
Scurvy	Dietary (vitamin C) deficiency	Lewis, 2004; Maat, 1982, 2004; Ortner, 2003: 385-87; Ortner et al., 2001; Ortner and Ericksen, 1997; Ortner et al., 1999; van der Merwe et al., 2010
Orbital porosity	Dietary deficiency, poor hygiene during childhood	Ortner, 2003: 363-75; Stuart-Macadam, 1987a, 1987b, 1991; Walker et al., 2009
Rickets and osteomalacia	Lack of UV light, dietary deficiency (vitamin D deficiency)	Brickley et al., 2005, 2007; Mays et al., 2006; Ortner, 2003: 393-403; Ortner and Mays, 1998; Schamall et al., 2003
Upper (maxillary sinuses) and lower (ribs) respiratory tract infection	High population density, poor living conditions, air pollution; poor oral health (sinusitis only)	Boocock et al., 1995; Roberts and Cox, 2007

♦, Antemortem tooth loss

(i) Dental diseases

For detailed analysis of the dental diseases, separate inventories for adult and non-adult dentitions were created. Firstly, each present, developing or erupting tooth, as well as those lost ante- and post-mortem, were recorded for all individuals. Secondly, caries, calculus, periodontal disease and enamel hypoplasia were recorded in the dental diseases inventory, either by tooth, or by quadrant (periodontal disease). Periapical lesions and dental attrition were recorded separately. All individuals with a present (even fragmentary) mandible or maxilla, or both, were included in the analysis.

The calculations for the prevalence of caries, calculus, periapical lesions and enamel hypoplasia were carried out both as the number of teeth affected/tooth sockets affected, and by the number of individuals with teeth/tooth sockets present to observe. Prevalence rates by tooth were calculated in order to give a better understanding of the number of observable teeth in different age and sex groups. However, statistical significance tests for dental diseases were only carried out using the prevalence rates by individual due to the highly variable presence/absence of affected teeth and sockets in every individual.

Prevalence rates by individual were based only on observable individuals for every dental disease, since it was felt that including individuals with unobservable jaws (neither upper nor lower) would skew the data (Waldron, 1994: 54). For all recorded dental diseases comparisons were made between adult males and females for analysis of possible differential diet and also to explore the care of boys and girls in childhood, as indicated by linear enamel hypoplasia, which only forms during that period (Hillson, 1996: 165-66).

a) Dental attrition

Dental attrition was recorded for all present anterior and posterior teeth following the diagrams of Murphy (1959) and Smith (1984). Teeth affected by severe caries or post-mortem damage, or where their occlusal surfaces were covered in calculus, were recorded as not observable.

b) Caries

Caries was classed as present if there was a visible lytic lesion penetrating the dental crown or the root and recorded as absent or present in every individual with at least one observable tooth. Caries was recorded in every affected tooth preserved for observation according to Lukacs (1989a), noting the location of the lesion on the tooth surface, where discernible, and also scoring each lesion as one of the following: a small pit, less than half the crown affected, more than half the crown, or all the crown involved. In prevalence calculations, only individuals with observable teeth (at least one) were included. Although data on the tooth classes affected were recorded for future analysis, it was not used in this research as, firstly, it lay outside its scope and, secondly, the data would not have been comparable with the data used from other Latvian or Baltic cemetery populations.

c) Periapical lesions

Periapical lesions were recorded as present if a distinctive smooth walled sinus in the alveolar bone was visible at the apex of the root (Ogden, 2008: 293-97). Every socket was treated as observable, even if the tooth had been lost ante- or post-mortem, as often a sinus can still be discernible in remodelling alveoli with the affected tooth lost antemortem. The lesions were recorded as present or absent, taking a note of the position of the sinus (external or internal, or penetrating into the maxillary sinus). To avoid recording pseudosinuses (post-mortem damage), the morphology of the sinus walls was observed with a hand lens (x 12 magnification).

d) Periodontal disease

Periodontal disease was assessed and recorded as suggested by Ogden (2008: 292-93), taking into account the morphology of the alveolar margin rather than the length of the exposed root. To avoid intra-observer error, the condition was recorded as absent or present by quadrant without scoring severity (anterior and posterior teeth - incisors and canines, and premolars and molars, respectively). Prevalence rates by individual for periodontal disease were also calculated by quadrant. Periodontal disease was recorded as observable even if only one tooth was present in the quadrant. Edentulous individuals, however, were excluded from the analysis.

e) Ante-mortem tooth loss

A tooth was considered as lost antemortem if the socket showed signs of remodelling or had completely remodelled. Care was taken to distinguish unerupted third molars in individuals with considerable ante-mortem tooth loss.

f) Calculus

The presence of calculus was assessed according to Brothwell (1981: 155), but to minimise intra-observer error and to enable inter-site comparisons it was recorded as present or absent on every tooth, and scored as slight, or medium to heavy. If the location of the deposit was below the gingival line, it was noted in the recording form, as sub-gingival calculus might be indicative of periodontal disease (Hillson, 1996: 262).

g) Enamel hypoplasia

Enamel hypoplasia was recorded as present only if the hypoplastic defects were visible without magnification. The tooth was recorded as not observable if considerable calculus deposits were present on the crown, or if most of the crown was missing due to extensive caries or post-mortem damage. For each observable affected tooth, the defects were recorded according to their type as linear, horizontal pits or furrows, or non-linear pits (Buikstra and Ubelaker, 1994: 56-7, Roberts and Connell, 2004). The type of the defects was recorded in order to better understand their possible cause (congenital or developmental) and thus to aid interpretation (Hillson, 1996: 165-66). The number of defects on each tooth was also recorded. Hypoplasia was scored as single or multiple (one, or more than one linear defects on the tooth). No attempt was made to calculate the age of formation of the defect as this was outside the scope of this research.

(ii) Cribra Orbitalia and possible anaemic changes

Cribra orbitalia (orbital roof porosity) was recorded in every adult and non-adult individual with at least one observable orbit preserved for observation, as defined by Stuart-Macadam (1991). A note of the appearance of the lesion (active or remodelled) was also made (Mensforth et al., 1978). The type and location of the lesion, however, was not distinguished, as only prevalence rates were to be considered. Moreover, only data for presence or absence of this condition was available from the comparative cemetery populations, and thus the data for type and location of the lesion would not be comparable. All individuals with sufficiently preserved skulls were also checked macroscopically for porotic hyperostosis of the skull vault and, where possible due to post-mortem breakage, for expansion of the diploë and thinning of the outer table of the skull (Ortner, 2003: 363-75, Stuart-Macadam, 1987a, 1987b).

(iii) Scurvy

To observe possible evidence for scurvy, different skeletal elements were examined in adult and non-adult individuals for a variety of pathological lesions. The porosity on the bones was treated as abnormal if dense, small, (less than 1mm in diameter) holes were penetrating the lamellar bone surface (Ortner and Ericksen, 1997). A hand lens (x 12 magnification) was used to aid the analysis. The pathological lesions were recorded as present or absent in all adult and non-adult individuals. A more detailed description was included in the recording forms for discussion of differential diagnosis.

In adult individuals, the orbits (Sloan et al., 1999), and left and right long bones (Fain, 2005, Wolbach and Howe, 1926) were analysed for new lamellar or woven bone formation, and the ribs for transverse fractures adjacent to the costochondral junction (Brickley and Ives, 2006, Maat, 2004, Sloan et al., 1999, van der Merwe et al., 2010). In non-adult individuals, new bone formation and/or abnormal porosity were recorded separately in orbits and the vault of the skull (external and internal), the sphenoid bone, mandible, maxilla, scapulae and long bones. The ribs were recorded for evidence of fractures or enlargement adjacent to the costochondral junction (Ortner, 2003: 386, Ortner et al., 1999). It is acknowledged that juvenile scurvy can affect new-born babies if the mother has been malnourished (Hirsch et al., 1976: 251); for this reason, non-adult individuals of all ages, including the youngest, were studied for possible abnormal cranial and post-cranial bone reaction. The analysis of very young individuals was aided by comparison of infants of similar ages to avoid recording developmental (age related) bone changes as pathological (Lewis, 2017: 3).

(iv) Rickets/osteomalacia

All individuals from the population were also analysed for possible evidence of vitamin D deficiency (rickets/osteomalacia). To find evidence for possible active rickets in non-adult individuals the skull vault was analysed for ectocranial new bone formation and/or abnormal porosity, and delayed closure of the fontanelles in individuals older than two years (Hess, 1930, Pettifor, 2003). In the post-cranial skeleton, ribs were observed for enlargement at the sternal ends, and long bones were analysed for abnormal bowing of the shaft and flaring of metaphyses, as well as abnormal porosity on growth plates (Hess, 1930, Mays et al., 2006, Ortner and Mays, 1998, Pettifor, 2003).

Residual rickets in adults was recorded as present if the pelvis presented deformities and if abnormal angulation was present in the long bones, particularly those of the legs (Brickley et al., 2005, Hess, 1930, Pettifor and Daniels, 1997). Fine porosity and “cardboard-like” consistency of the bones of the skull, as well as deformities and/or fractures in the pelvis and ribs, were interpreted as evidence of adult osteomalacia (Mankin, 1974, Pitt, 1988). The pelvis and ribs, as well as scapulae, forearm bones and femora were also analysed for pseudo-fractures (Brickley et al., 2005, 2007, Hess, 1930, Schamall et al., 2003). All changes were recorded as present or absent.

(v) Pulmonary infection and sinusitis

Every observable individual maxillary sinus and the visceral surfaces of preserved ribs were observed for signs of reactive (woven) and healed (lamellar) new bone formation and/or porosity. Maxillary sinusitis was assessed and recorded as present if abnormal porosity and/or new bone formation, active or remodelling, was present in the sinus walls (Boocock et al., 1995). A note was made if there was a periapical lesion with drainage into the maxillary sinus. Individuals with complete skulls with little post-mortem damage, were classed as not observable. Both sinusitis and rib lesions were recorded as present or absent.

3.2.3 Statistical analysis

For contrasting dental attrition scores between different demographic groups and contexts, Kruskal-Wallis and Mann-Whitney tests were used. When comparing three or more groups, a Kruskal-Wallis test was used, followed by a post-hoc Mann-Whitney test, if the result was statistically significant. To compare prevalence rates for all dental diseases and all other pathological lesions, a Chi-Square test was used on samples larger than five, and a Fisher's Exact test for smaller samples. For comparative analysis of stature estimates, unpaired t-tests were used. In all tests, the significance level was set at 0.05.

To compare $^{87}Sr/^{86}Sr$ ratios from enamel, dentine and animal bone samples, a Kruskal-Wallis test was used for more than two groups, and a non-directional Mann-Whitney test for two groups, with α level at 0.05.

3.2.4 Biogeochemical methods

In order to help determine individual and population differences in diet and possibly origin between the three different contexts of the St Gertrude's cemetery, carbon, nitrogen and strontium isotope analyses were carried out on selected individuals from all three contexts. Carbon and nitrogen isotope analyses of incremental dentine in the teeth of non-adult individuals was also used in order to assess the possibility of identifying nutritional stress shortly before death, especially in people buried in the mass graves. The methods used for sample preparation in all biogeochemical analyses are described in detail in sections (i) and (ii) below.

(i) Carbon and nitrogen

Carbon and nitrogen stable isotope analyses were carried out on 96 selected individuals from the mass graves (22 and 23 samples from each mass grave, respectively) and the main cemetery (51 sample) to determine possible dietary differences. Individuals from each context were primarily selected according to availability of ribs, or rib fragments. For carbon and nitrogen analysis, 1-2g of bone was taken from the ribs (with preference given to unidentified rib fragments to reduce the destruction of the skeletal remains). The samples were then taken to University's Pollen and Isotopic Analysis Laboratory in the Department of Archaeology for bone collagen preparation, using the modified Longin (1971) method (Richards and Hedges, 1999). To extract the collagen, the bone samples were demineralised in 0.5M HCI (hydrochloric acid solution) at 4°C for 5-6 weeks; rinsed with deionized water and transferred to falcon tubes with a pH3 HCl acid solution; gelatinised at 70°C for 48 hours; and finally, Ezee-filtered, frozen, and freeze-dried. The prepared samples were measured using the facilities of the School of Archaeological and Forensic Sciences, University of Bradford.

To explore the diet of individuals shortly before death, permanent canines without carious lesions and with the root still forming (between seven and 14.5 years, according to AlQahtani et al. 2010) were collected from twelve non-adult individuals from the two mass graves (six from each) and five from the general cemetery, in order to carry out incremental dentine analysis (Beaumont et al., 2013). To increase the sample size, a lower second incisor and a lower second premolar from two individuals of a similar age were also selected from the general cemetery. The teeth were prepared for collagen extraction as described by Beaumont et al. (2013 - from Kirsanow et al. 2008), using Method 2. Teeth which had more than one half of the root complete were cut in half longitudinally before processing; less developed teeth were processed whole. The enamel of the tooth was removed with a diamond saw and retained for strontium isotope analysis. The remaining dentine and root were demineralised as described above (Richards and Hedges, 1999), and 1mm cross-sections were then cut with a sterile scalpel against a metal ruler, starting from the coronal dentine and moving towards the root. The sections were then rinsed with deionised water, placed in sealed microtubes with pH3 hydrochloric acid, and gelatinised at 70^{o}C for 24 hours. The resulting solution was not filtered, only centrifuged, then frozen, and freeze-dried. To estimate the duration of formation for each increment, the time between initial crown formation (C_i), and the mid-point of the approximate age at death, based on AlQahtani et al. (2010) was divided by the number of increments. The samples were analysed in the Department of Earth Sciences, Durham University. Details on the measurement process for this analysis can be found in Chapter 5.

(ii) Strontium

Strontium isotope analysis ($^{87}Sr/^{86}Sr$ ratio) was carried out from the core enamel of the same 19 individuals sampled for the incremental dentine analysis described above, to explore further the possibility that the people buried in the mass graves might be rural migrants from the Vidzeme region. It was hypothesised that in this case the strontium isotope ratios for the individuals in the mass graves would be largely similar and would differ from the general cemetery population.

Since geological strontium isotope ratios have not yet been studied in the Latvian soils and rocks, seven environmental samples were also collected (four animal bone samples from other contemporary cemeteries in Riga, and three from cemeteries in Vidzeme region) in order to observe bioavailable strontium isotope ratios (Bentley, 2006, Sillen et al., 1998, van der Merwe et al., 2003). Geological maps and survey results were used to complement the data (Gilucis and Segliņš, 2003, Zelcs et al., 2011).

First, the surface enamel on each tooth was removed with a tungsten carbide dental burr (Montgomery, 2002). Second, the core enamel was removed with a flexible diamond impregnated cutting disc diagonally from the cusp. The enamel samples were then inspected for any remaining dentine or impurities, which, if present, were removed with the burr. In addition, four dentine samples were taken from the tooth crown. Finally, the samples were sealed in micro-centrifuge tubes. The samples were analysed in the Department of Earth Sciences, Durham University. Further details on sample preparation and analysis can be found in Chapter 6.

Chapter 4. Manuscript 1

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Dental disease and dietary isotopes of individuals from St Gertrude Church cemetery, Riga, Latvia

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Abstract

This research explores oral health indicators and stable carbon and nitrogen isotope data to explore diet, and differences in diet, between people buried in the four different contexts of the St Gertrude Church cemetery (15th – 17th centuries AD): the general cemetery, two mass graves, and a collective mass burial pit within the general cemetery. The main aim is to assess whether people buried in the mass graves were rural immigrants, or if they were more likely to be the victims of plague (or another epidemic) who lived in Riga and its suburbs. The data produced (from dental disease assessments and isotope analyses) were compared within, as well as between, the contexts. Most differences emerged when comparing the prevalence rates of dental diseases and other oral health indicators in males and females between the contexts, while isotope analysis revealed more individual, rather than context-specific, differences. The data suggested that the populations buried in the mass graves were different from those buried in the general cemetery, and support the theory that rural immigrants were buried in both mass graves. Significant differences were observed in some aspects of the data between the mass graves, however, possibly indicating that the people buried in them do not represent the same community.

1. Introduction

This study focuses on the skeletons excavated from the St Gertrude Church cemetery, Riga, Latvia, dating from the late 15th – 17th centuries AD (Figs 1 and 2). The church was located outside the old city wall during the period of its use, and mainly serviced Gertrude village (Pīrangs, 1932). Although it is believed that the Gertrude village population was moderately wealthy and lived in less crowded conditions than the inner-city population, historical evidence suggests that the suburbs of Riga were destroyed three times between the 15th and 17th centuries by the authorities of Riga ahead of invading armies (Dunsdorfs, 1962). Moreover, during the excavation, two mass graves and a smaller mass burial pit were discovered within the general cemetery. Historical evidence suggests that the people buried in these mass burial sites could have been either the victims of an epidemic or rural immigrants who came to Riga during a devastating famine at the beginning of the 17th century (Actiņš et al., 2009, Pīrangs, 1932, Rusovs, 1926).

Fig 1. Map of Latvia.

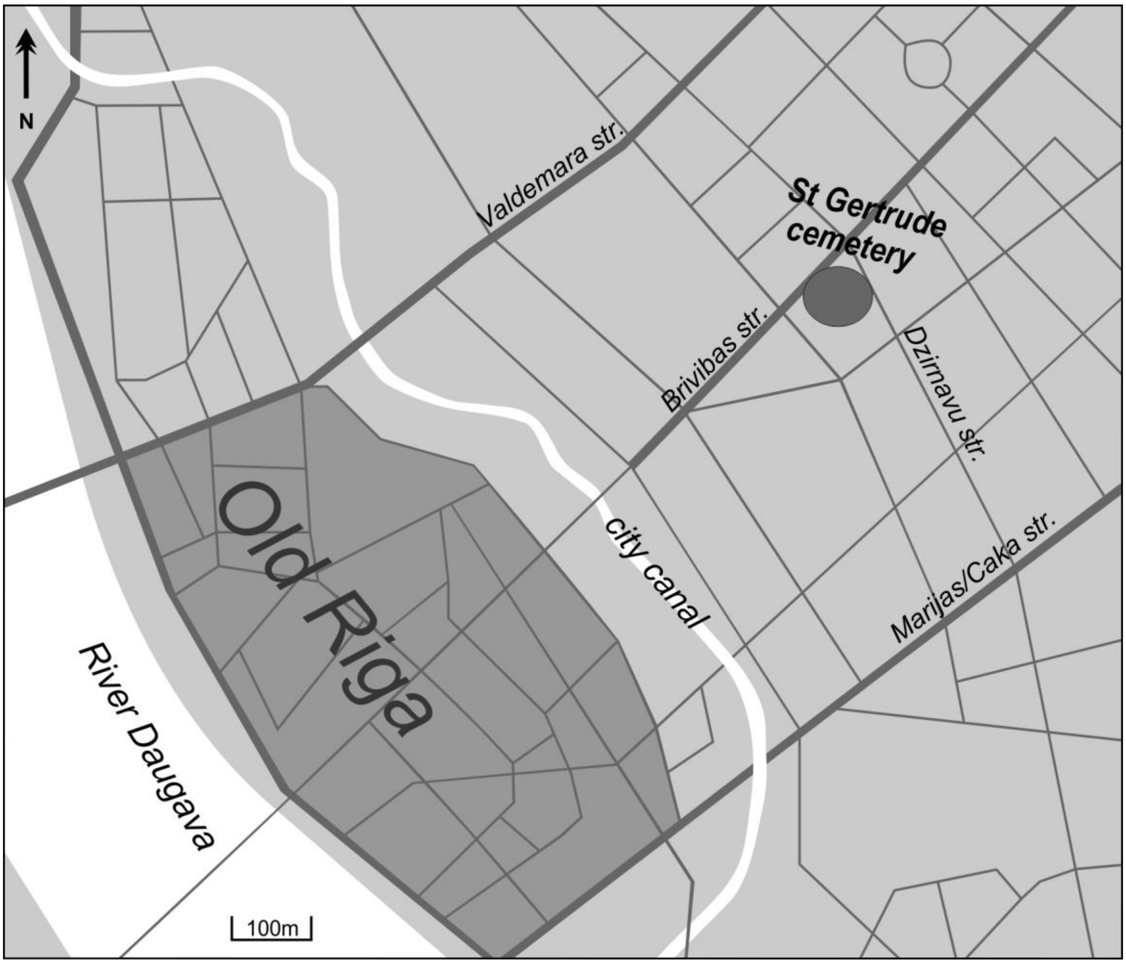

Fig 2. Location of St Gertrude Church cemetery in Riga.

This research aims to explore the diet of the people buried in the general cemetery and mass graves, by comparing the prevalence of dental disease, calculus, as well as attrition scores in all individuals, and dietary isotope profiles in the adult population, to identify if there were differences in the people interred in the different burial complexes (the general cemetery, two mass graves, and burial pit). Since dental attrition, caries, periodontal disease, and calculus are important indicators of diet, these conditions are used here to reconstruct diet and general dental health. A comparative analysis of oral health indicators between the burial contexts will further confirm whether there is variation in frequencies that indicate different population groups. Data on oral health indicators are complemented by carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope analyses, which provide insights into the dietary status of the population. The three hypotheses proposed are:

1) Most individuals buried in the general cemetery were from the local area and thus represent a moderately wealthy, urban, population with access to softer dietary carbohydrates, such as finely ground bread, and foods that are accepted as linked to

higher status, such as meat. This is predicted to be expressed in a higher prevalence of "destructive" dental diseases (caries, periodontal disease), lower dental attrition rates, and higher $\delta^{15}N$ values, indicative of more animal protein in their diet;

2) Most individuals buried in one, or both, mass graves represent poor rural immigrants. This is predicted to be expressed in a lower prevalence of destructive dental diseases, higher dental attrition rates, and lower $\delta^{15}N$ values, indicating a diet dominated by plants;

3) Most individuals buried in one, or both, mass graves represent victims of plague, or another epidemic disease, who lived in Riga and/or its vicinity. This scenario is predicted to be expressed in similar attrition scores and prevalence rates of dental pathological conditions and $\delta^{13}C$ and $\delta^{15}N$ values, in line with people from the general cemetery.

1.1 Historical background and a comparison of living conditions in urban and rural areas during the post-medieval period

St Gertrude church was built around 1413 AD outside the old centre of Riga, to accommodate the city's growing population and to provide shelter for travellers. The church was located on the main route to the east, leading to the Vidzeme region, of which Riga is the capital, and further afield to Estonia and Russia (Pīrangs, 1932).

St Gertrude's Cemetery mostly received the local, moderately wealthy suburban community from Gertrude village and its vicinity (Pīrangs, 1932), but the cemetery has also been mentioned in historical sources as the final resting place for other population groups and plague victims (Actiņš et al., 2009, Rusovs, 1926). Notably, in the winter of 1601-2, poor immigrants from rural Vidzeme flocked to Riga in search of food, but were forced to camp outside the city walls near St Gertrude church, where they died in great numbers from hunger and cold; the deceased were most likely buried in the cemetery (Actiņš et al., 2009, Pīrangs, 1932, Rusovs, 1926). The presence of mass graves in the cemetery supports the historical evidence and suggests that people buried there could represent a different, possibly poor rural, population. Alternatively, victims of the plague from Riga and its suburbs could also be present in the mass graves, since St Gertrude graveyard is mentioned in historical sources as one of the burial places for 17th century plague victims (Pīrangs, 1932:

501). There were at least two plague epidemics in Riga, in 1601 and 1623, according to Bodecker's chronicle (Napiersky, 1890).

The population of Gertrude village mostly comprised peasants and craftsmen (Šterns, 1998: 349-55). There is evidence that the peasants of Riga and its suburbs had increased freedom from their landowners, compared to most peasants from rural areas (Dunsdorfs, 1962: 253). The status of Riga as a key trading centre provided them with direct access to resources arriving into the city, possibly including goods from newly acquired European colonies in Africa and America, such as sugar (Zeids, 1978: 149). There is also evidence for numerous beehive trees near Gertrude village, and it is possible that villagers could use this resource in their diet, especially if they were involved in honey harvesting (Šterns, 1998: 349). The better social status of peasants from Riga, combined with accessibility to Riga's markets, might well have had a positive effect on the quality of the diet of these people, as expressed in more variation in dietary sources, and probably more animal protein in general, compared to that available to the poor rural populations (see below). Although the suburban population of Riga benefited from less crowded living conditions than within the city walls, they were much less protected than the city population, especially during warfare. Most buildings were constructed from wood to allow the authorities to burn down the suburban areas ahead of sieges. This was done to destroy potential shelter and resources for the invading army. The suburbs of Riga were thus deliberately destroyed in 1559, 1605 and 1710. The city also allegedly suffered from several famines and plague epidemics in the 16th to 18th centuries, mainly due to frequent conflicts (Dunsdorfs, 1962). According to historical sources, such disasters affected the availability of resources for all social groups regardless of status and wealth throughout the region, and thus could have affected the health status of the living population at least to some extent. This was the case for a wealthy post-medieval German population buried in Jelgava, Latvia, where a recent study found evidence for nutritional stress in children, as expressed in high rates of cribra orbitalia and scurvy. The presence of these conditions in non-adult skeletons, combined with high rates of linear enamel hypoplasia in adult individuals, was interpreted as evidence for possible hardships during frequent wars, famines and epidemics during the lifetimes of these people (Pētersone-Gordina et al., 2013).

With regard to the rural peasant population, it is believed that their living conditions were poorer than those of the urban population in most regions of Latvia. The majority of people in the countryside were peasants, who were the subjects of German landowners. These people had to work in the landowners' farms to make them profitable, but they were not allowed to use the produce of the farm for subsistence; as a result, they had to work in their own allotments after they returned from work on the farm, in order to feed themselves and their families. Due to the limited size of the allotments, as well as minimal input of work, there was rarely any leftover produce to sell in the markets, and transporting the produce to the market would have been difficult for those living in remote areas (Dumpe, 1999: 119). An account of the diet of Latvian and Estonian peasants suggests that the quality of meals depended on the season, with the period between Christmas and early summer being the leanest, while salted fish, as well as butter were available in the summer, and meat was eaten on Sundays during the autumn and winter (Hueck, 1845: 99). The availability of these foodstuffs, however, would have differed across regions. Indeed, previous studies on the stature of post-medieval cemetery populations from Latvia have revealed that the lowest statures characterized rural peasant populations from the poorest regions (Gerhards, 2005b). Stature that is reduced according to the norm for a population from a particular geographic region has been linked to poor health and/or undernutrition in developing countries today (Addo et al., 2013, Leonard, 1989, Martorell, 1980), and in many archaeological populations (Goodman, 1991a: 33, Schug and Goldman, 2014).

1.2 Criteria for the selection of the oral health indicators used in this study, and their brief aetiologies

The dental pathological conditions studied for this research were chosen according to their potential to reveal information about diet and to test the three hypotheses proposed. It was believed that the oral health indicators which are largely related to diet (dental attrition, caries, periodontal disease, periapical lesions, ante-mortem tooth loss, and calculus deposits), would best highlight differences between the individuals buried in the general cemetery and the mass graves. Indeed, many have synergies. The presence and extent of dental attrition, as reflected in skeletal remains from archaeological sites, often depends on the coarseness of the diet, as well as the amount of abrasive particles in the food (Brothwell, 1981: 71, Mickleburgh, 2016). Some archaeological studies have linked slight dental wear in combination with high caries rates to soft and sticky foods in the diet, which is taken to be indicative of increased wealth in archaeological populations (Keenleyside, 2008, Larsen, 2015: 76).

Caries formation is a slow and gradual process caused by organic acids, which are known to form in the fermentation process of dietary carbohydrates, and sugars in particular, by plaque bacteria (Adler et al., 2013, Hillson, 2005: 291, Larsen et al., 1991: 179, Selwitz et al., 2007, Zero et al., 2008: 338). Caries is highly prevalent in industrialised populations, routinely affecting 60-90% of schoolchildren and most adults (World Health Organization, 2016b). It is believed to have increased considerably with the advent of a sedentary lifestyle in the past, since this was consistent with eating an increased proportion of carbohydrates, such as those derived from farmed crops (Larsen, 1995, Larsen et al., 1991). The introduction of refined sugar from the European colonies to Europe in the post-medieval period caused a rapid deterioration of dental health. Initially only the wealthy had access to sugar, but eventually it became more widely available for the whole population (Adler et al., 2013). This has also been shown by high caries rates recorded in a high-status 17th century population from Jelgava, Latvia, who were known to have access to refined sugar (Pētersone-Gordina and Gerhards, 2011). Consequently, significant differences in caries prevalence rates between post-medieval populations might point to differential proportions of carbohydrates in the diet, as well as access to refined sugar. A number of bioarchaeological studies have proved that older individuals and females are generally more likely to develop the lesions (Cucina and Tiesler, 2003, Keenleyside, 2008, Larsen, 2015: 72, Larsen et al., 1991, Lukacs, 1996, 2008, Palubeckaite et al., 2006, Saunders et al., 1997, Watson et al., 2010). Higher caries rates in females in archaeological populations have most commonly been explained by gender differentiation of diets (Cucina and Tiesler, 2003) and the demands of pregnancy (Boldsen, 1998, Cucina and Tiesler, 2003, Larsen et al., 1991, Lukacs, 1996, 2008). In addition, some evidence suggests that an increase of oestrogen levels in female saliva during pregnancy could be responsible for higher rates of caries in this sex group (Lukacs and Largaespada, 2006: 547). This is supported by a recent clinical study, which showed increased levels of salivary Streptococcus mutans, a type of the bacteria which has been linked to development of caries, in pregnant women (Featherstone, 2000, Kamate et al., 2017).

Caries-induced infection of the pulp cavity is believed to be one of the most common reasons for the development of periapical lesions (Hillson, 1996: 284, 2008: 322, Sivapathasundharam, 2009: 490), and their presence might be indicative of dental decay even when the teeth have been lost ante- or post-mortem. Severe attrition also can lead to infection, once the pulp cavity is exposed (Hillson, 2008: 322). On the other hand, there are several types of periapical lesions, including granulomata and cysts, and not all necessarily become infected during a person’s life (Ogden, 2008: 293-7). Distinguishing between benign and infected periapical lesions and their causes in archaeological populations can be difficult, and thus their presence cannot be readily taken as evidence for poor dental health (Dias and Tayles, 1997).

Periodontal disease, like caries, has been found to have a strong relationship to plaque bacteria (Axelsson et al., 2004, Marsh et al., 2009: 117), and therefore the prevalence of both conditions is often similar in archaeological populations (Hillson, 2008: 321); this was also the case in the high-status Jelgava population, mentioned above with regard to high caries rates (Pētersone-Gordina and Gerhards, 2011). Likewise, periodontal disease tends to have a higher prevalence in populations which consume soft, processed foods (Huynh et al., 2016). Clinical data show that increased levels of psychological stress can exacerbate periodontal disease in populations today (Genco et al., 1998, Hugoson et al., 2002). Its main consequence is alveolar bone loss, which is most likely caused by advanced bacterial infection of the gingiva (the soft tissue surrounding the teeth) (Tonetti et al., 2015). In this study, periodontal disease was viewed in relation to caries, as a potential indicator of the consumption of carbohydrates in the diet.

Caries, and especially periodontal disease, are among the leading causes for ante-mortem tooth loss (AMTL) (Larsen, 2015: 77, Marsh et al., 2009: 117, Ogden, 2008: 288). In archaeological studies on historical populations, AMTL has been viewed in relation to differences in social status, with wealthier individuals often exhibiting better oral health and thus, lower rates of AMTL, compared to people of lower social status; these differences were explained by a higher proportion of protein and a comparatively low amount of carbohydrates in the diet of high-status individuals, as opposed to poorer members of the society (Cucina and Tiesler, 2003, Frayer, 1984, Girotti and Doro-Garetto, 1999). The main aim of including AMTL in this study was to provide an approximate indicator of overall dental health, while the proportion of protein in the diet of people buried in St Gertrude's cemetery population is estimated by dietary isotope analysis.

Dental plaque is characterized by a film of micro-organisms covering the tooth surface in living people (Hillson, 2005: 254, Selwitz et al., 2007). Mineralised plaque, or calculus, deposits are very common on the teeth of archaeological skeletons (Brothwell, 1981: 160). Calculus formation on the teeth depends on various factors such as components in the diet and an inherited predisposition (Hillson, 2005: 289). With regard to diet, it has been found that calculus deposits tend to increase in agricultural populations due to diet dominated by soft, cooked carbohydrates, as opposed to more fibrous food used by hunter-gatherers, which is consistent with changes in the composition of plaque bacteria in response to different dietary practices (Huynh et al., 2016). On the other hand, recent clinical studies have shown that considerable amounts of an amino-acid, L-arginine, which is naturally found in red meat, poultry and milk, effectively removes dental plaque (Kolderman et al., 2015, Tada et al., 2016). It is not currently known, however, if a diet rich in animal protein would also act against plaque bacteria developing. In this study, the presence and amount of calculus is considered with regard to the other plaque-related diseases of caries and periodontal disease.

1.3 A brief overview of carbon and nitrogen isotope analysis

Carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope analyses of collagen were employed in this research in order to provide a more detailed insight into the diet of the people buried in the cemetery. This method of analysis cannot detect carbohydrates unless protein consumption is extremely low and thus cannot directly support evidence for a high prevalence of destructive dental disease. However, it remains a useful tool in detecting the proportion of animal ($\delta^{15}N$) and marine proteins in the diet ($\delta^{13}C$). Different $\delta^{13}C$ and $\delta^{15}N$ values might help to distinguish if there were:

- groups of people from different regions (closer and further from the coast),
- differential access to animal protein, and/or
- different diets for males and females

Moreover, certain animal (milk, cheese) and marine (fish) proteins have the potential to prevent dental decay (Zero et al., 2008: 334-5) and therefore the results of macroscopic and isotopic analyses are cross-compared.

Since the first use of carbon and nitrogen stable isotope analyses in relation to exploring diet in past populations (DeNiro and Epstein, 1978, 1981, van der Merwe and Vogel, 1978, Vogel and van der Merwe, 1977), they have become one of the most important means of studying dietary choices (Ambrose, 1991, Ambrose et al., 2003, Katzenberg et al., 2012, Mays, 1997, 2010, Vanderklift and Ponsard, 2003, Wilhelmson, 2017). Isotope analysis is of particular importance in archaeology due to its potential to detect different food sources and, most importantly, how these sources were used by different age, sex and status groups within the same population. In essence, $\delta^{13}C$ values reflect the presence of food chains based on plants with different photosynthetic pathways in the diet (C_3 and C_4 plants, which grow worldwide and mainly in tropical regions, respectively), as well as the contribution of marine resources to the diet (Harrison and Katzenberg, 2003). In Northern European studies, especially with regard to periods before the introduction of C_4 plants such as maize from the 16th century onwards (Janick and Caneva, 2005), $\delta^{13}C$ values are mainly used to study the proportion of marine resources in the diet (Mays, 1997, Pollard and Heron, 2008: 358). According to previous studies, a diet based entirely on marine resources will yield $\delta^{13}C$ values of around -12‰, while a C_3 diet with minimal or no marine input will result in $\delta^{13}C$ values around -21‰ (McGovern-Wilson and Quinn, 1996, Richards and Hedges, 1999, Schoeninger, 1989, Spielmann et al., 1990, Tauber, 1986). In contrast, a diet based on C_4 plants will yield values of -14‰, or higher (Deines, 1980), and could indicate access to imported grains in post-medieval northern European populations.

The only source of nitrogen in the diet is protein (Chisholm et al., 1982, Hedges et al., 2004). $\delta^{15}N$ values reflect the trophic level of living organisms, and therefore they can be used to detect the proportion of animal protein as well as marine or freshwater resources in the human diet (Ambrose et al., 2003, Brown and Brown, 2011: 84). While it is not possible to accurately estimate the percentage of animal protein in the diet, a higher $\delta^{15}N$ value does indicate a higher proportion of meat or secondary animal proteins, such as milk (Ambrose et al., 2003, O'Connell and Hedges, 1999). Likewise, due to substantially higher $\delta^{15}N$ values in fish compared to terrestrial resources, the presence of marine or freshwater resources in a diet will also be expressed as higher $\delta^{15}N$ values in bone collagen samples (Katzenberg, 1989, 2008: 426).

2. Material

Seven hundred and twenty-one skeletons were excavated from St Gertrude's cemetery (Latitude 56.954818, Longitude 24.119343) between August and October 2006 prior to planned building works. The archaeological excavation was carried out by Architectural Research Group Ltd (SIA AIG) and supervised by Mārtiņš Lūsēns, with permission No 2006/A-0000466 issued by the State Inspection for Heritage Protection (VKPAI). Since the skeletal remains found during the excavation were older than 100 years, no permissions were required for their research in accordance with the law On the Protection of the Body of Deceased Human Beings and the Use of Human Tissues and Organs in Medicine, 1992 (The Supreme Council of the Republic of Latvia, 1992). The excavated skeletal material (collection number 104) is curated at the Institute of Latvian History, University of Latvia, Kalpaka bulv. 4, Riga. The material is accessible for research by prior arrangement in accordance with the Institute's regulation No 2015/253.

During the excavation, apart from recovering burials from the general cemetery, two mass graves (MG) were discovered in the south-eastern (MG1) and north-western (MG2) corners of the excavated area, containing 166 and 120 individuals, respectively. In total, there were 435 individuals in the general cemetery (GC), including the burial pit (BP), and 286 in the mass graves (Table 1). Individuals in the mass burials were not commingled, and the preservation of their skeletons was very good in all contexts.

Table 1. Number of individuals in each context of the cemetery.

Context	*Males*	*Females*	*Adults*	*Non-adults*	*Total*
GC	115	100	18	187	420
MG1	63	48	0	55	166
MG2	46	34	0	40	120
BP	3	9	0	3	15

In this study, comparative dental pathological and isotope analyses were carried out on the groups from the GC and MGs; the analyses were based on differences in diet, reflected in carbon and nitrogen isotope values, rather than strontium ($^{87}Sr/^{86}Sr$ ratio) and oxygen ($\delta^{18}O$) isotope analyses, which are usually applied to study population origins and mobility (Katzenberg, 2008: 430). However, a separate pilot study comparing $^{87}Sr/^{86}Sr$ ratios in permanent canines from selected non-adult individuals from the cemetery is underway to add to the findings of the current research.

3. Methods

3.1 Osteological methods

Sex estimates of adult individuals were based on morphological traits of the pelvic girdle and skull (Buikstra and Ubelaker, 1994: 16-20, Milner, 1992, Phenice, 1969), with the pelvic data having precedence, if available. Age at death estimates in adults were mainly based on degeneration of the pubic symphysis and auricular surface of the os coxae, using degenerative changes in the sternal ends of the ribs, and cranial suture closure, where this was not possible (Brooks and Suchey, 1990, Buckberry and Chamberlain, 2002, Işcan et al., 1984a, Işcan et al., 1984b, Loth and Işcan, 1989, Lovejoy et al., 1985, Meindl and Lovejoy, 1985). To estimate age in non-adult individuals, dental formation and eruption were used (AlQahtani et al., 2010), as well as epiphyseal fusion and long bone measurements (Fazekas and Kósa, 1978, Maresh, 1970, Ogden et al., 1978, Schaefer, 2008).

Before prevalence analyses were conducted, chi-square statistical significance tests were used to compare the adult age and sex distribution. The distribution of young (18-30 years old) and middle to older individuals (over 31 years old) was not significantly different between the contexts (χ^2 (1, N=226) =0.06, p=0.806). The same was true for the distribution of sex groups for young males and females (χ^2 (2, N=88) =0.44, p=0.802) and older males and females (χ^2 (2, N=138) =5.6, p=0.06). Because the main aim of this research was to compare specific oral health indicators to see if the population groups in each context had different origins, and based on the equal distribution of age and sex groups, the prevalence of dental diseases in men and women is given for both adult age groups together. Data on prevalence for caries, periapical lesions, periodontal disease and ante-mortem tooth loss by age group (18-30 and over 31-year-old individuals) can be found in S4.6 Table (Supplementary Material S4).

Due to the low prevalence of dental disease in non-adult individuals, and to achieve suitable sample sizes, they were not divided into age groups. A statistical test was performed to control for different age structures in each burial context in order to avoid age bias in specific dental conditions, and particularly attrition scores. There was no statistically significant difference in the distribution of children aged between six and 11, and 12 and 17 years who had at least one observable permanent tooth between the contexts (χ^2 (2, N=83) =4.99, p=0.082). Likewise, no statistically significant differences were observed when comparing individuals with at least one observable molar, for attrition analysis (χ^2 (2, N=67) =5.66, p=0.059).

Deciduous and permanent teeth were analysed separately. Otherwise, dental pathological conditions and attrition were recorded similarly in adults and non-adults.

3.2 Palaeopathological methods

Dental attrition was recorded for all present permanent teeth following the diagrams of Murphy (1959) and Smith (1984). These methods, which use modal forms rather than individual drawings, were chosen for their simplicity of use and comparability, as well as the reduced possibility of intra- and inter-observer error. The wear on all teeth was recorded in order to control for possible heavy activity-related wear rather than dietary induced wear. Individuals with possible activity-related wear were excluded from this analysis. Teeth affected by severe caries or post-mortem damage were recorded as not observable. The overall attrition for teeth in skeletons from each context was calculated by averaging the wear of the first maxillary and mandibular molars (M1), as suggested by Lunt (1978). The analysis was performed both overall, and according to age group in adults (18-30, and 31+ years old).

The presence of caries was documented for every permanent and deciduous tooth according to Lukacs (1989b), and recorded as absent or present in every individual with at least one observable tooth. Caries was classed as present if there was a visible lytic lesion penetrating the dental crown or the root of the tooth. Erupting teeth clearly above the alveolar margin were also recorded as observable.

Periapical lesions were recorded as present if a distinctive smooth walled sinus in the alveolar bone was visible at the apex of the root (Ogden, 2008: 293-7). Every socket with an erupting/erupted tooth was treated as observable, even if the tooth had been lost ante- or post-mortem. The lesions were recorded as present or absent. To avoid recording pseudosinuses as a result of post-mortem damage, the morphology of the sinus walls was observed with a hand lens (12x magnification).

Periodontal disease was assessed and recorded as suggested by Ogden (2008: 292-3) taking into account the morphology of the alveolar margin rather than the length of the exposed root. To avoid intra-observer error, the condition was recorded as absent or present by quadrant without scoring severity (anterior and posterior teeth - incisors and canines, and premolars and molars, respectively). True prevalence rates were also calculated by quadrant. Periodontal disease was recorded as observable even if only one tooth was present. Edentulous individuals were excluded from the analysis.

A tooth was considered as lost ante-mortem if the socket showed signs of remodelling, or had completely remodelled. The presence of calculus was assessed according to Brothwell (1981: 160), but to minimise intra-observer error it was scored as slight (1) or medium to heavy (2) on every tooth.

To decide if dental attrition scores were statistically significantly different between different demographic groups and contexts, Kruskal-Wallis and Mann-Whitney tests were used. When comparing three or more groups, a Kruskal-Wallis test was used, followed by a post-hoc Mann-Whitney test if the result was statistically significant. To compare prevalence rates for all other dental diseases, a chi-square test was used on samples larger than five, and a Fisher's Exact test for smaller samples. In all tests, the significance level was set at 0.05. Only p values are given in the text, but the details of the calculations are given in Table

S4.5 (Supplementary Material S4). All osteological and palaeopathological analyses were carried out by one observer, thus excluding any possibility for inter-observer error; to avoid intra-observer error, most lesions were scored as absent and/or present.

3.3 Isotope analysis

Carbon and nitrogen stable isotope analyses were carried out on 96 selected adult individuals from the mass graves (22 samples from MG1 and 23 samples from MG2) and the main cemetery (46 samples), as well as the BP (five samples) to explore possible dietary differences and to complement the findings of the dental analysis. Non-adults were not analysed isotopically in this study. Seven additional samples were analysed from a contemporary Jelgava Holy Trinity Church cemetery population, Latvia, in a different region to see if regional differences between the two cemetery populations were expressed in different $\delta^{13}C$ and $\delta^{15}N$ values. These samples were taken from the skeletons of children aged 1-2 years (J15, J22, J33), 2-3 years (J97), 3-4 years (J95, J98), and 4-5 years (J40). For calculations of statistically significant differences in values, a Kruskal-Wallis test was used to compare three or more groups, with a post-hoc Mann-Whitney test if the result was statistically significant. Mann-Whitney test was used to explore comparisons between two groups, with the significance level set at 0.05 for both tests. Linear correlation and regression analysis by Pearson product-moment correlation coefficient was performed on all $\delta^{13}C$ and $\delta^{15}N$ values from the St Gertrude population, whereby $r = +1.0$represents a perfect positive correlation, $r = -1.0$ a perfect negative correlation, while $r = 0.0$ signifies a complete absence of correlation. The purpose of these analyses was to determine if the values were influenced by differing proportions of marine sources in diet (Richards and Hedges, 1999).

For carbon and nitrogen isotope analysis, 90-200mg of bone were taken from the ribs or the scapulae. These skeletal elements were chosen because they were often already fragmented due to post-mortem damage, thus minimising any new damage to skeletal remains during sample collection. The samples were prepared for collagen extraction, following a modified Longin (1971) method (Richards and Hedges, 1999). To extract the collagen, the bone samples were demineralised in 0.5M HCI (hydrochloric acid solution) at 4°C for 5-6 weeks. The demineralised samples were rinsed with deionized water and transferred to falcon tubes with a pH3 HCl acid solution, before gelatinisation at 70°C for 48 hours. The samples were then Ezee-filtered, frozen, and freeze-dried.

The prepared collagen samples were measured in duplicate at the School of Archaeological Sciences, University of Bradford, by combustion in a Thermo Flash EA 1112 and introduction of separated N_2 and CO_2 to a Delta plus XL via a Conflo III interface. Laboratory and international standards were interspersed throughout each analytical run. The results are expressed using the delta notation in parts per thousand (per mil or ‰) relative to the international VPDB standard for carbon and atmospheric nitrogen for the nitrogen as follows:

$$\delta^{15}N = R_{sample}/R_{standard} - 1,$$

where *R* is the isotope ratio $^{15}N/^{14}N$ or $^{13}C/^{12}C$ (Coplen, 2011). The error for the carbon and nitrogen isotope ratio measurements determined from repeated measurement of international and laboratory standards did not exceed +/- 0.2‰, 1 standard deviation. One sample from Jelgava (J40) yielded a higher than recommended C:N ratio (3.6) (van Klinken, 1999: 691), signalling contamination; this was therefore not used for further analysis. All collagen yields were above 5%.

4. Results

4.1 Age and sex distribution

The reconstructed demographic profile suggests a catastrophic mortality for those buried in both mass graves (Gerhards, 2009a), whereby most age and sex groups are equally distributed due to being equally susceptible to the cause of death. By contrast, attritional mortality profiles will demonstrate a focus on certain age and sex groups, for example, infants and very young children, and older adults (Keckler, 1997). This was particularly true for the non-adult population, whereby the mass graves contained fewer young individuals, and substantially more older children, than were present in the general cemetery (Fig 3). There were nine females, three males and three non-adult individuals in the BP. All adults were over the age of 30, and the youngest child was 7-8 years old at death. Because of the small sample size, these individuals were combined with the GC population for palaeopathological and isotope analyses.

It was not possible to estimate age for 22 males and 28 females from the GC, two males and three females from MG1, and four males and three females from MG2, and therefore these individuals were not included in the demographic profile.

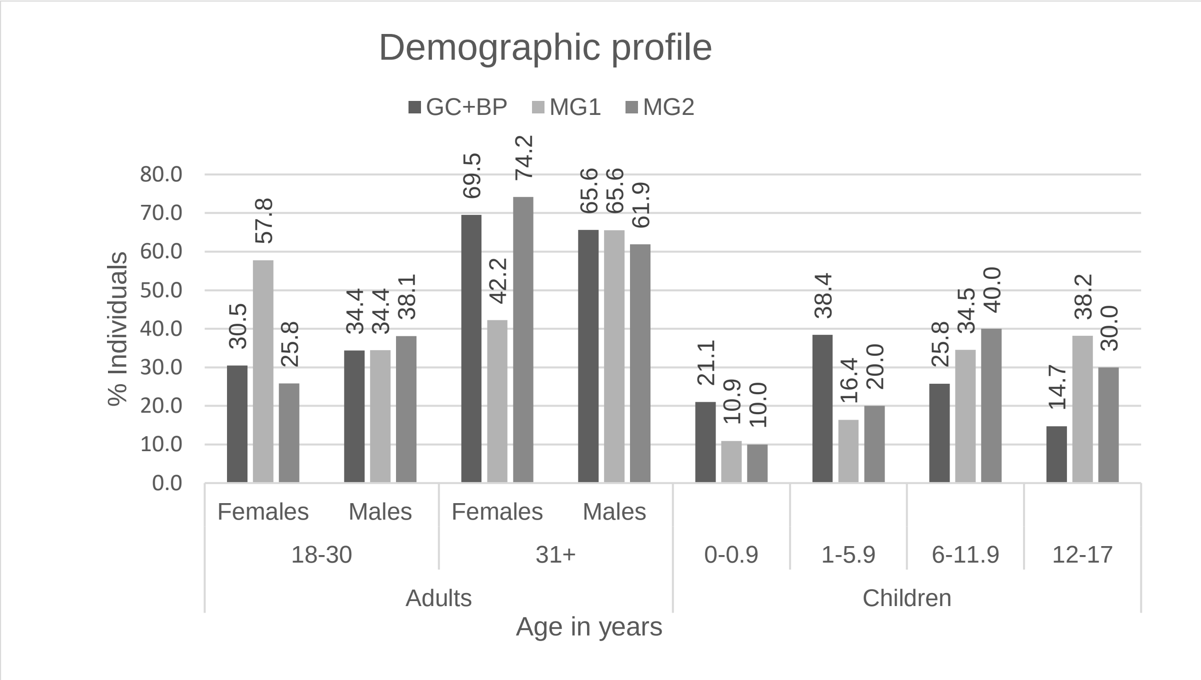

Fig 3. Demographic profile of the population.

4.2 Dental disease

4.2.1 Attrition of M1

In total, 193 adult individuals had at least one observable first molar, and 606 adult molars were observed for severity of attrition. No evidence for activity-related wear was observed. Overall, males from both mass graves had the highest attrition scores, while males and females from the GC, as well as females from MG2 had the lowest (Fig.4). The distribution of scores was not substantially different between females from all contexts (p=0.475) but it was significantly different in young males (p=0.013). Attrition scores also proved to be significantly different between older males and females from MG1 (p=0.028) and young and older males and females from MG2 (p=0.007 and p=0.004, respectively).

Seventy-two non-adults had at least one observable M1 (25 from the GC, 32 from MG1 and 15 from MG2). The average M1 attrition scores were similar for MG2 and the GC, while individuals from MG1 had the highest scores (Fig 4). Attrition proved to be significantly higher in MG1 than in both, the GC (p=0.015) and MG2 (p=0.037). In total, 254 first molars were observed in non-adults.

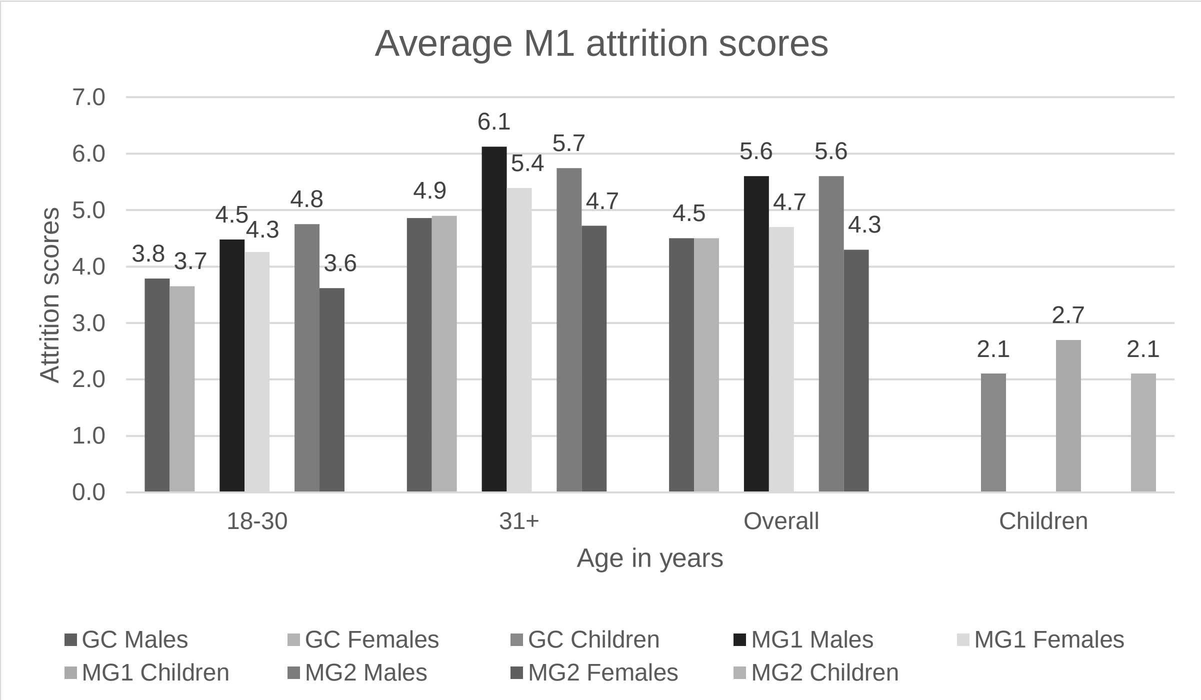

Fig 4. Average M1 attrition scores in all contexts.

4.2.2 Caries, periapical lesions, periodontal disease, and AMTL

Caries could be observed in 225 adult individuals who had at least one tooth. All observed individuals and teeth/alveoli/quadrants for these conditions can be seen in Table 2. Overall, caries rates were above 50% in all groups, except in females from the GC. Males from the GC had the highest caries rates overall (61.4%), while females from this context had the lowest (40.0%). The difference, however, was not statistically significant (p=0.082). Caries prevalence rates in the sex groups between the contexts were not substantially different.

Table 2. Caries, periapical lesions, periodontal disease and AMTL in the adult population by individual, and by tooth/alveolus/quadrant count.

	By individual				By tooth/alveolus/quadrant			
	F	%	M	%	F	%	M	%
Caries								
GC	16/40	40.0	27/44	61.4	41/693	5.9	72/921	7.8
MG1	17/29	58.6	26/52	50.0	48/601	8.0	56/1114	5.0
MG2	14/25	56.0	19/35	54.3	31/513	6.0	48/750	6.4
Periapical lesions								
GC	14/40	35.0	18/44	40.9	24/1014	2.4	42/1285	3.3
MG1	10/29	34.5	19/52	36.5	24/847	2.8	40/1518	2.6
MG2	7/25	28.0	20/36	55.6	18/744	2.4	38/1032	3.7
Periodontal disease								
GC	11/40	27.5	18/44	40.9	52/265	19.6	85/326	26.1
MG1	10/29	34.5	20/52	38.5	45/220	20.5	120/405	29.6
MG2	9/25	36.0	16/36	44.4	47/189	24.9	61/270	22.6
AMTL								
GC	25/40	62.5	23/44	52.3	135/1014	13.3	137/1285	10.7
MG1	17/29	58.6	31/52	59.6	77/847	9.1	127/1518	8.4
MG2	16/25	64.0	21/36	58.3	108/744	14.5	87/1032	8.4

F-females; M-males; GC-general cemetery; MG1, MG2-mass graves; AMTL-ante-mortem tooth loss

The highest prevalence of periapical lesions in adults was observed in males from MG2 (55.6%), while the lowest prevalence was observed in females from this context (28.0%). The difference was not statistically significant between these groups (p=0.062), and the lesions were also equally distributed between sex groups from the other contexts. Accordingly, the prevalence rates of periapical lesions were not consistent with those of caries, discussed above.

Periodontal disease did not show substantial differences between same sex groups from different contexts. Likewise, the differences between sex groups in the same contexts were not pronounced. Males from MG2 had the highest prevalence of the condition (44.4%), while females from the GC had the lowest (27.5%) (Table 2).

Ante-mortem tooth loss affected over 50% of people from all contexts, although the prevalence was somewhat higher in females from the GC and MG2 (62.5% and 64.0%, respectively). There were no pronounced differences in prevalence rates either between, or within, the contexts (Table 2).

In the non-adult population, there were low caries rates in both deciduous and permanent teeth (Table 3). Overall, 20 of 158 individuals (12.6%) with at least one erupted deciduous and/or permanent tooth were affected. There were no individuals with caries affecting both permanent and deciduous dentition.

Table 3. Caries in the non-adult population by individual and by tooth count.

	By individual						By tooth					
	D	%	P	%	Total	Total %	D	%	P	%	Total	Total %
GC	3/84	3.6	4/38	10.5	7/98	7.1	6/744	0.8	5/376	1.3	11/1120	2.1
MG1	2/22	9.1	6/35	17.1	8/40	20.0	3/150	2.0	11/630	1.7	14/780	3.7
MG2	3/20	15.0	2/19	10.5	5/26	19.2	5/171	2.9	2/302	0.7	7/473	3.6

D-deciduous; P-permanent

The lowest overall (deciduous and permanent) caries rates were in the children from the GC (7.1%), while in MG1 and MG2 they were substantially higher (20.0% and 19.2%, respectively). The difference between caries rates in the GC, MG1 and MG2 was not statistically significant (p=0.054). The youngest individuals with caries in the deciduous dentition were 4-5 years old (individuals GC 280 and MG1 572). In both, deciduous molars were affected.

Only one non-adult individual had a periapical lesion (burial 340, 17-19 years old, from MG1). It affected the root of the right mandibular M1, which had been lost ante-mortem. Periodontal disease and AMTL were not observed in children.

4.2.3 Calculus

In the adult population, calculus deposits were present on the dentitions of most adults (Fig 5). The lesions affected slightly fewer females than males, especially with regard to the GC and MG2. In the non-adult population, calculus deposits affected individuals with both permanent and deciduous teeth. In total, most individuals affected derive from MG2 (18 of 26, or 69.2%) followed by MG1 (26 of 40, or 65.0%), but there were only 21.1% children (20 of 95) with calculus deposits on the permanent and/or deciduous teeth in the GC. The difference between the GC and MG1 and the GC and MG2 was statistically significant (both p<0.001). Individuals from MG1 and MG2 had a relatively high prevalence of dental calculus on their permanent dentitions (24 of 40, or 60.0% and 13 of 26, or 50.0%, respectively), while only 13 of 95, or 13.7% of individuals were affected in the GC. With regard to calculus deposits on deciduous teeth, the highest prevalence rates were in individuals from MG2 (nine of 26, or 34.6%), while fewer non-adults were affected from MG1 and the GC (four of 40, or 10.0%, and nine of 95, or 9.5%, respectively).

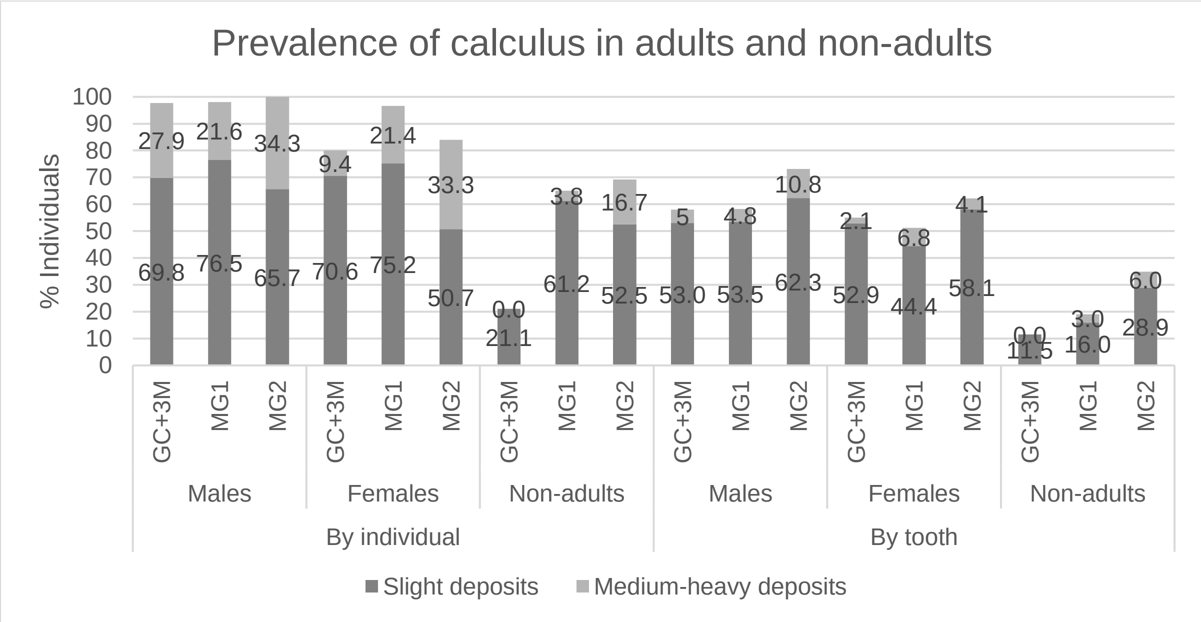

Fig 5. Prevalence of medium-severe calculus deposits in adults and children; only total (deciduous and permanent) prevalence is given in this figure for calculus in children.

There were no children with medium-severe calculus deposits from the GC, affecting either deciduous or permanent dentitions. In MG1, one individual had heavier deposits on both deciduous and permanent teeth (Individual 490 from MG1, aged 15-16 years at death). In MG2, although no individuals with deciduous teeth had heavier calculus deposits, there were three non-adults with permanent dentitions affected.

Analysis of the amount of calculus revealed more differences in adults between contexts, than the total prevalence. Males from MG2 proved to have the highest prevalence of medium-severe lesions in this sex group, and overall (12 of 35, or 34.3%), while only 9.4% (three of 32) of females from the GC had heavier calculus deposits, compared to over 20% in females from the other two contexts (six of 28 and seven of 21 in MG1 and MG2, respectively). The difference was statistically significant between females from the GC and MG2 (p=0.038), but not between the GC and MG1 (p=0.281).

The number of observed individuals and teeth for this analysis is given for adults in Table S4.7 and for non-adults in Table S4.8 (Supplementary Material S4).

4.3 Results of isotope analysis

The range of $\delta^{15}N$ values in the St Gertrude's cemetery was between 8.7‰ and 13.7‰ (both values from individuals from the GC), and the range of $\delta^{13}C$ values was between -21.2‰ and -18.9‰ (also both from the GC). In Jelgava, $\delta^{15}N$ values ranged between 13.5‰ and 15.3‰, and $\delta^{13}C$ values between -20.3‰ and -19.7‰. Detailed measurement data for isotope analysis can be observed in Table S4.9 (Supplementary Material S4). Results of carbon and nitrogen isotope analyses revealed a clear division in $\delta^{15}N$ values between the populations of Jelgava and St Gertrude (Fig 6).

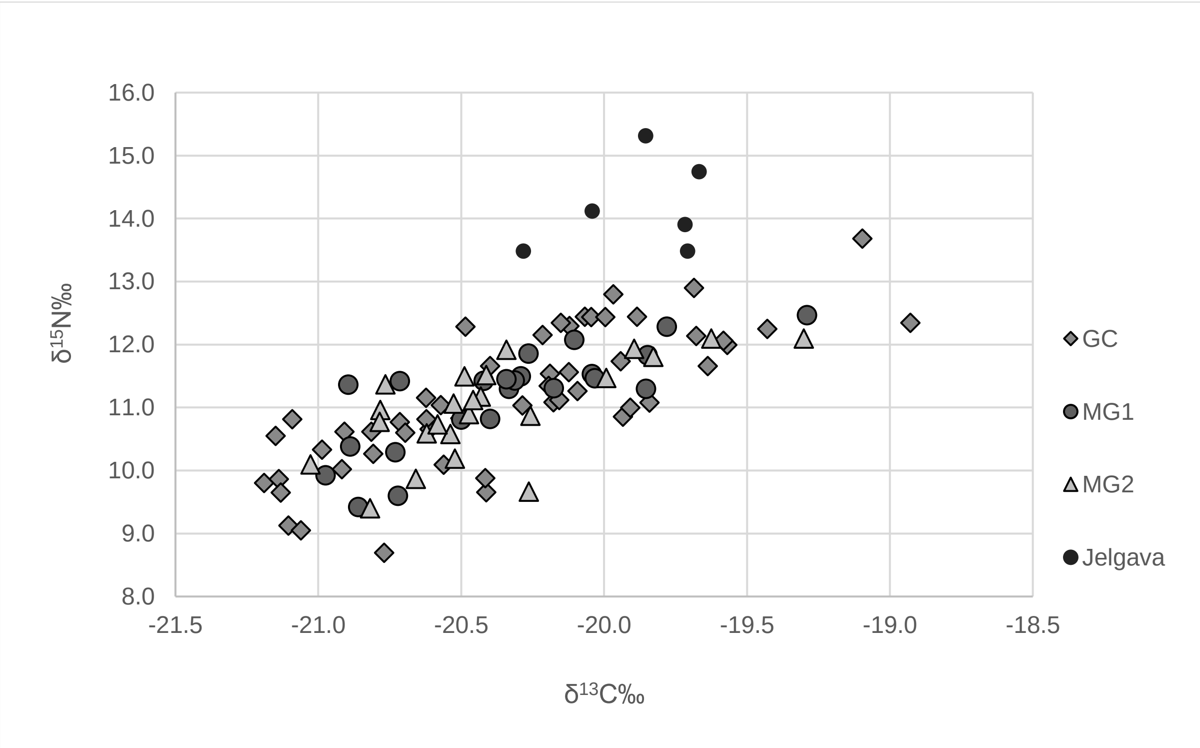

Fig 6. $\delta^{13}C$ and $\delta^{15}N$ values in the St Gertrude and Jelgava populations.

Most individuals had $\delta^{15}N$ values below 13.0‰, except individual 92 (male, 45-55 years old, from the GC). In the Jelgava population, however, all $\delta^{15}N$ values were above 13.0‰.

As seen in Fig 6, $\delta^{13}C$ and $\delta^{15}N$ values in St Gertrude population correlate positively (both increase and/or decrease in concert). Linear correlation analysis resulted in r=0.8.

When the individuals from the cemetery were divided into males and females, a number of patterns in the $\delta^{13}C$ and $\delta^{15}N$ value distributions emerged. Males from the GC had higher mean $\delta^{15}N$ and $\delta^{13}C$ values than females from the same context (Table 4). In MG2, while males had higher $\delta^{13}C$ values, $\delta^{15}N$ values were higher in females. In MG1, males had lower $\delta^{13}C$ and $\delta^{15}N$ values than females, and the lowest average $\delta^{13}C$ values in the population. Females from MG1 had the highest $\delta^{15}N$ values.

Table 4. Mean $\delta^{15}N$ and $\delta^{13}C$ values in the adults and children from Jelgava.

Context	Males					Females				
	n	$\delta^{13}C$	SD	$\delta^{15}N$	SD	n	$\delta^{13}C$	SD	$\delta^{15}N$	SD
GC	31	**-20.1**	0.55	**11.3**	1.17	20	**-20.6**	0.45	**10.9**	0.90
MG1	10	**-20.5**	0.49	**11.1**	0.89	11	**-20.2**	0.32	**11.4**	0.76
MG2	15	**-20.4**	0.37	**10.9**	0.74	8	**-20.4**	0.49	**11.1**	0.85
		Jelgava children								
	6	**-19.9**	0.24	**14.2**	0.73					

n-number of individuals; SD-standard deviation

There were no statistically significant differences in the distribution of $\delta^{15}N$ values between males and females from all contexts (p=0.257 and p=0.243, respectively). Likewise, the differences in $\delta^{15}N$ values between sex groups from the same contexts were not statistically significant (p=0.078 (GC), p=0.379 (MG1) and p=0.401 (MG2)). The differences in $\delta^{13}C$ values, however, were more pronounced. Although the distribution was not significantly different in males from all contexts (p=0.101), $\delta^{13}C$ values proved significantly higher in females from MG1 than females from the GC (p=0.012). $\delta^{13}C$ values did not significantly differ between females from the GC and MG2 (p=0.390) and females from both mass graves (p=0.126). With regard to differences between the sexes in the same contexts, $\delta^{13}C$ values were significantly higher in males than females from the GC (p=0.005), and significantly lower in males than females from MG1 (p=0.037). The differences between males and females from MG2 were not statistically significant (p=0.772).

5. Discussion

5.1 Variation in diet as expressed by dental disease

The first differences between the three contexts emerged when comparing dental attrition rates, indicating that the relative coarseness of the diet varied between males, females and children. The observed attrition rates were significantly lower in young males from the GC than young males from both mass graves, and significantly lower in females than males from both mass graves. This was also partly the case in non-adult individuals, with attrition rates significantly lower in the GC and MG2 than MG1. This suggests that young males from both mass graves, and children from MG1, had a coarser diet than most other people buried in the cemetery. Although bread was a staple food in post-medieval Latvia (Dumpe, 1999: 122-7), its coarseness differed across regions and/or individual populations, resulting from either different milling techniques (by hand, or in a wind or water powered mill) or inclusion of other plant material in the flour, or both. For example, according to historical sources, peasants in some regions had hand mills and made their own flour, and the resulting flour had a high proportion of bran, as well as bits of straw, mixed in with it (Lentilius, 1924). There are also accounts of various wild grasses, as well as moss, being added to bread in years of poor harvest (Oekonomisches Repertorium für Liefland, 1808-1811, Repository of Ethnographic Material of the Institute of Latvian History, University of Latvia). On the other hand, the flour ground in mills for the upper classes was finely sieved, thus leaving out bran and other particles (Hueck, 1845). Moreover, cereal grains were used in different meals, including porridge, and not just in bread (Hueck, 1845, Hupel, 1774-1782, Straumīte, 1906), and they might have been cooked differently in some population groups according to the age and/or sex of the people. This might have been the case for most males, females and children buried in MG2. The observed differences in dental attrition rates are in support of hypotheses one and two, and suggest that different population groups are present in all three contexts. A more detailed study including the attrition of all types of teeth would be necessary to further explore the findings of this study.

With regard to caries in adults and non-adults, there were no significant differences in the same sex groups between the contexts, despite the varied attrition rates discussed above. It can therefore be concluded that in the overall population, attrition was not linked to caries prevalence. One of the possible explanations for the inconsistent results might be more abrasive particles in the diet of some groups, as discussed above, rather than a smaller proportion of carbohydrates.

The comparatively lower caries rates in females from the GC are difficult to explain. If these individuals had a higher proportion of products which are known to prevent the disease, such as milk, cheese, or sea food in their diet compared to males (Hillson, 1996: 279, Zero et al., 2008: 334-5), then this would likely be expressed in higher $\delta^{13}C$ and/or $\delta^{15}N$ values. This, however, was not the case (see the following section).

The highest prevalence of periapical lesions in males from MG2 seemed to be linked to dental attrition, rather than caries. As detailed above, this can be explained by severe attrition, whereby the dental pulp cavity is exposed and thus becomes infected (Hillson, 2008: 322). In males from the GC, however, the high prevalence of periapical lesions did seem to be linked to high caries rates, whereby the pulp became exposed because of advanced dental decay. However, a higher prevalence rate might have been detected in all groups if radiographic analysis had been carried out.

With regard to periodontal disease and AMTL, it seems inconsistent that males from MG2 had the highest rates of periodontal disease, despite having the highest attrition rates. As mentioned above, periodontal disease is often associated with softer diets. Since the condition was recorded by observing the alveolar margin, rather than the length of the exposed root, this discrepancy in frequency rates is unlikely to have occurred because of attrition initiated continuous eruption (Ogden, 2008: 293-7). It is therefore likely that periodontal disease in groups with higher attrition rates was the result of bacterial activity in the dental plaque, regardless of a coarser diet (Axelsson et al., 2004, Hillson, 1996: 262, Orland et al., 1954). It is also possible that psychological stress was an additional factor in the development of the disease in males from MG2 (Genco et al., 1998, Hugoson et al., 2002). This, however, would be difficult to test in an archaeological population. In males from the GC, however, the low attrition is consistent with a high prevalence of periodontal disease. Given the high rates of destructive dental diseases in the population discussed above, the over 50% AMTL prevalence in all contexts and sex groups does not seem unusual.

While the lack of statistically significant differences in the prevalence of caries, periapical lesions, periodontal disease and AMTL between any of the demographic groups in this study supports hypothesis three, it can be argued that similarly high amounts of carbohydrates, as discussed above, contributed to relatively equal rates of the four conditions in all contexts. As shown by significant differences in dental attrition rates, however, the main differences in diet between the groups seem to have been based on its coarseness, as discussed above.

Moving on to calculus, the significant differences in the prevalence of medium-severe deposits between females from the GC and MG2, as well as the total prevalence between children from the GC and both mass graves, might indicate a difference with regard to the amount and/or composition of dietary carbohydrates in these groups. Chemical analysis of the calculus deposits would be necessary to confirm any differences in the composition of dietary carbohydrates between the people buried in different contexts. On the other hand, recent clinical studies suggest that certain amino-acids, which are naturally present in red meat, poultry and milk, have a potential to remove dental plaque, if used in concentrated amounts (Kolderman et al., 2015, Tada et al., 2016). If considerable dietary intake of such animal protein did have any impact on lower prevalence of plaque, it would be expressed in higher $\delta^{15}N$ values. This was not the case in St Gertrude's cemetery population, whereby no statistically significant differences in $\delta^{15}N$ values were observed between the groups (see the following section). Alternatively, the observed differences in heavy calculus deposits might be a result of differential survival in the burial environment (Freeth, 2000), or differential presence and severity on particular teeth, which might be related to teeth having been lost ante- or post-mortem. A more detailed analysis of dental calculus by the number and type of affected teeth would be necessary to further explore the differences.

In summary, the differences in oral health indicators discussed above provide sufficient evidence to support hypotheses one and two, that people buried in the GC and mass graves represent three different population groups, even though the prevalence of destructive dental disease did not prove to be statistically significant between them.

While it is likely that the populations were different, it is not possible to confirm by dental analysis alone whether either of the populations from the mass graves comprised rural immigrants. A recent study comparing dental caries, AMTL and periapical lesions in post-medieval cemetery populations in Latvia found that there were no particular patterns for rural and urban, as well as high and low status populations (Pētersone-Gordina and Gerhards, 2011). The lack of a pattern was explained by the different political situations in the observed regions; Latvia was divided between Sweden and the Polish-Lithuanian Commonwealth during the period in question, with land mainly in the hands of German landowners. The possible differences between cultural beliefs, fertility demands, availability of food and the general quality of life were also suggested as causes. The study also found that there were substantial differences even between two neighbouring rural cemetery populations in Vidzeme, likely due to different diet. With regard to comparative studies from other Baltic countries, two contemporary populations from Estonia (rural Tääksi, and urban Pärnu St John's Church cemetery) both yielded very similar rates of caries and periapical lesions as observed in the St Gertrude's cemetery population (Allmäe, 1999, Limbo, 2009). The lack of similar patterns in dental disease between urban and rural populations from Latvia, and the scarcity of data from other post-medieval Baltic populations, made a regional comparison with the St Gertrude's cemetery difficult.

5.2 Dietary differences as expressed by isotope analysis

As shown in Fig 6, the population of Jelgava had substantially higher $\delta^{15}N$ values than St Gertrude. Geographically, the city of Jelgava is situated inland, adjacent to the River Lielupe (Fig 1). The high $\delta^{15}N$ values in this population may therefore be explained by the presence of fish from the River Lielupe in their diet. Alternatively, some influence of breastfeeding is also possible in the three younger children (below two years of age) from this population, since during breastfeeding, $\delta^{15}N$ values of infants have been shown to be 2-3‰ higher compared to their mothers or wet-nurses in modern and archaeological populations (Eerkens et al., 2011, Fogel et al., 1989, Fuller et al., 2006). Ethnographic and historical evidence suggests that most children in past Latvian populations were fully weaned by the age of two years (Muktupāvela, 2005). This would mean that the $\delta^{15}N$ values in older children would be closer to those of the adult population. In the absence of adult data from the Jelgava population, it is hypothesised that the $\delta^{15}N$ values above 13.0‰ in all children, compared to St Gertrude's population, are more likely to be the result of a higher proportion of freshwater fish in the diet, rather than breastfeeding, although a further study is necessary to fully test this hypothesis. The Jelgava population was used in this study in order to explore obvious differences between two contemporary cemetery sites, and thus to aid discussion of the possible presence of populations of different origins who were buried in St Gertrude's cemetery. This first step to comparative analysis pointed to substantial dietary differences between the Jelgava and St Gertrude populations, but no differences between the groups within St Gertrude's cemetery. However, the region of Vidzeme from which the rural migrants are believed to have derived (Actiņš et al., 2009, Pīrangs, 1932, Rusovs, 1926) has a long coastline. Consequently, populations living close to the coast might well be isotopically indistinguishable from those living in Riga.

The positive correlation coefficient for $\delta^{13}C$ and $\delta^{15}N$ values in people from St Gertrude cemetery suggests that the observed values were mainly influenced by a marine component in their diet, rather than differential terrestrial $\delta^{13}C$ sources. The lack of a consistent pattern by context, however, is suggestive of high individual variability in the amount of marine protein in the diet of the whole population. Nevertheless, small differences in $\delta^{13}C$ and $\delta^{15}N$ values for the people buried in St Gertrude's cemetery became apparent when they were analysed by sex.

The $\delta^{15}N$ values were not significantly different between the contexts, indicating that most people had similar amounts of protein in their diet. With regard to significant differences observed between $\delta^{13}C$ values in females from MG1 and the GC, and between the sex groups in these two contexts, the absolute mean $\delta^{13}C$ values in all groups only differed by 0.4‰. This amount is too small to suggest meaningful dietary differences between any groups, with regard to the marine component, as was also supported by the lack of significant differences in $\delta^{15}N$ values. Indeed, differences in $\delta^{13}C$ values might also be caused by small temporal variations in the local terrestrial $\delta^{13}C$, which are influenced by environmental factors such as solar radiation, temperature, and moisture (Farquhar et al., 1989, Heaton, 1999, van der Merwe and Medina, 1991).

The apparent lack of freshwater resources in the diet of the population is surprising, considering that they lived by a large river, and that freshwater fish were routinely caught by the local fishermen to be sold in the markets (Caune, 1992: 127-8). It seems that instead, the population relied to a far greater extent on fish from the sea. Historical evidence suggests that salted fish was not only readily sold in Riga, but also transported to inland markets (Hueck, 1845). The good storage properties of salted fish might have made them cheaper than fresh fish, and thus perhaps more available to the local population.

At the beginning of this study it was expected that dietary isotope analysis would be consistent with specific destructive dental diseases, and caries in particular. As discussed above, marine protein, similar to certain milk products, can prevent the development of dental caries (Zero et al., 2008: 334-5), and a correlation between a high proportion of marine fish in the diet and low caries rates has been found in other archaeological studies (Hillson, 1996: 279, Stroud and Kemp, 1993, Zero et al., 2008: 334-5). In this study, however, despite the significant differences observed in $\delta^{13}C$ values between some groups, meaningful differences in the amount of marine protein in the diet could not be detected. It is possible that the proportion of marine resources in the diet of this population was too low to have any impact on dental decay, especially if carbohydrates were a dietary staple, as discussed above. This is also supported by the mean $\delta^{13}C$ values of all groups being above -20.0‰, close to terrestrial end-point in diet (-21.0‰), and with no individual values exceeding -19.0‰. Likewise, the prevalence of dental diseases and the dietary carbon and nitrogen values observed in St Gertrude's cemetery are consistent with data from Roman Winchester, whereby relatively high caries rates in the population were also explained by a diet based predominantly on carbohydrates (Bonsall and Pickard, 2015).

6. Conclusion

The main aim of this paper was to explore if there were different population groups buried in the St Gertrude's cemetery, based on differences in the prevalence of dental pathological conditions and attrition and dietary stable isotope values.

Firstly, there were differences between contexts with regard to dental attrition and calculus deposits. Although most contrasts were observed between mass graves and the GC, there was also evidence for differences between the mass graves, mainly expressed by significantly higher attrition rates in children from MG1 than in both other contexts. This evidence supports the possible presence of more than one population group in the mass graves, albeit with more similarities between them when compared to Gertrude villagers buried in the GC. The lack of significant differences in destructive dental disease between any of the groups is suggestive of a similar amount of carbohydrates in their diet.

The results of the dietary stable isotope analysis, however, did not support evidence for the presence of different populations when compared by context. The individuals from all three groups were spread across the observed range for both $\delta^{13}C$ and $\delta^{15}N$. The observed variability of $\delta^{13}C$ values suggested that all groups had equal access to marine fish and/or other marine protein, but that it was accessed differentially among individuals, without clear evidence for any pattern by context and/or sex groups. Likewise, no significant differences were found in $\delta^{15}N$ values between any groups. The low mean and individual $\delta^{13}C$ values also suggest that the marine input in the diet of the whole population might have been too low to have any preventative effect on destructive dental disease.

The three hypotheses of this study were only partly supported, because evidence for several population groups being present in the cemetery was not fully supported by all observed variables. However, as discussed above, it is possible that local populations living in close proximity to the sea, and/or inland with regular access to salted fish, might be isotopically indistinguishable. Further research is ongoing to look at strontium isotope data from selected individuals in each context, which might help to identify any migrants, and thus provide further evidence about the population groups buried in St Gertrude's cemetery. Furthermore, aspects of general health, including indicators of interrupted growth in childhood, will also be compared between the contexts.

Currently, there is a lack of similar studies from the region, hampering comparisons with other contemporary coastal and/or inland populations, especially with regard to dietary isotope values. This study is therefore an important addition to the published literature, having generated comparable and detailed data on oral health indicators, as well as a set of much needed reference dietary isotope values, which can be readily used in the future by researchers all over the Baltic region.

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Chapter 5. Manuscript 2

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Investigating dietary life histories and mobility in children buried in St Gertrude Church cemetery, Riga, Latvia (15^{th} – 17^{th} centuries AD)

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Key words: diet, famine, stable isotopes, carbon, nitrogen, collagen, mobility

Abstract

Carbon and nitrogen isotope profiles were obtained from incremental dentine analysis of 19 non-adults from a cemetery in Riga, Latvia. The research aimed to identify rural immigrants in two mass graves, and to compare their diet with the general cemetery population. The $\delta^{13}C$ profiles of several children from the mass graves were similar but did not resemble patterns in children from the general cemetery, suggesting that they probably represented a different population group. The rise in $\delta^{15}N$ values towards the end of life in four individuals from one mass grave suggests that they were victims of a historically documented famine.

1. Introduction

This study is based on 19 non-adult individuals excavated from St Gertrude Church cemetery in Riga, Latvia (Figure 1). The cemetery dates from the 15th – 17th centuries and was partly excavated ahead of planned building works on the site between August and October 2006. During the excavation, two mass graves were discovered in addition to the single discrete burials. The site offered a rare opportunity to study short-term dietary changes from birth to death in children who died during a mass mortality event, and to reveal several aspects of life and death in this suburban community by applying high-resolution incremental analysis.

The mass graves were believed to contain immigrants from the rural region of Vidzeme, of which Riga is the capital, who migrated to the city during a famine in the beginning of the 17th century (Napiersky 1890). A previous study on dental disease in the whole population, found significant differences in dental attrition scores between the three contexts, the general cemetery and two mass graves, suggesting that different populations were present in the cemetery; carbon and nitrogen isotope analysis in adults, however, did not find substantial dietary differences between the individuals (Petersone-Gordina et al., 2018). The results of isotope analysis were explained by the possibility that due to the close proximity of the coast to both Riga and a large part of Vidzeme, as well as evidence for the consumption of salted fish by the local population both in Riga and inland Vidzeme, the populations might be isotopically indistinguishable. The authors therefore hypothesised that detailed dietary analysis through dentine incremental analysis which would show dietary patterns over several years, would help to distinguish any migrants in the mass graves.

Figure 1. Map of Latvia, showing Riga, Vidzeme and the location of Latvia in Europe.

Incremental dentine analysis to study seasonal variation in diet was first attempted on faunal remains (Balasse et al., 2001, Kirsanow et al., 2008), and later on human teeth (Fuller et al., 2003). The recent development of high-resolution dentine sampling, whereby much smaller dentine samples are necessary for obtaining sufficient amount of collagen (Eerkens et al., 2011), has enabled analysing short-term changes in diet and/or dietary stress episodes, as demonstrated by Beaumont and co-workers in a study of the skeletons of probable Irish migrants to London during the Great Irish Famine (Beaumont et al., 2013). In essence, this analysis measures carbon and nitrogen isotope ratios in several consecutive dentinal increments from a single tooth, mapping yearly dietary changes, as well as possible stress episodes in an individual's life throughout the formation process of the tooth. Incremental dentine analysis is based on the fact that unlike bone, primary dentine does not remodel after it is formed (Nanci, 2003), thus retaining information about childhood diet and stress episodes throughout the individual's life; moreover, it grows at regular intervals every year (Dean and Scandrett, 1995), which allows for relatively precise sampling, and assigning chronological age for each increment (Beaumont and Montgomery, 2015). As a result, each increment provides an average of values for the period of its formation (Beaumont et al., 2013).

For this research, a key purpose was to look for any diet or stress related changes before death, using incremental dentine analysis. In particular, the idea was to explore whether these diet or stress related changes were present in migrants who had come to Riga during a purported famine, who were at death buried in one, or both, mass graves. For this reason, only teeth which were still in the process of formation at the person's death were selected. The aim of this study was to establish childhood diet in non-adult individuals from the early months of their lives to their deaths from all three contexts. The objective was to compare their individual life histories and possible differences in diet.

The main hypotheses that are addressed are

1) that children from populations in Riga and nearby rural regions accessed available food resources differentially, especially marine and terrestrial protein, which would be expressed in detectable differences in incremental dentine profiles;
2) that if the children in mass graves were rural immigrants who came to Riga during a famine, their diet as expressed in isotopic values is expected to have changed not long before death in most of these individuals, while any evidence of change should be more varied in children from the general cemetery.

1.1 Historical background

The Church of St Gertrude is first mentioned in historical sources in 1413. It was built outside the old centre of Riga, and its main purpose was to provide shelter for travellers. It also became the main church for the suburban Gertrude village, named after the church. The church and the village were situated on the main route to/from the east, leading to the Vidzeme region, and further afield to and from Estonia and Russia (Pīrangs, 1932). The cemetery was used as the final resting place for people of Gertrude village, as well as travellers who died in Riga and did not belong to any of the city's congregations. Moreover, St Gertrude's cemetery is mentioned in historical sources as one of the burial places for plague victims from Riga and its suburbs (Pīrangs, 1932: 501). Two plague epidemics are reported in Riga in the 17th century, in 1601 and 1623 (Napiersky, 1890). The burial ground went out of use in the late 17th century after the church of St Gertrude was destroyed and rebuilt elsewhere.

Gertrude village was small, and its population mostly comprised farmers, servants and craftsmen with their families. The close proximity of the village to Riga, which was a key trading centre during the post-medieval period, provided the population with access to various resources arriving into the city (Dunsdorfs, 1962).

While the villagers seemingly had good access to resources, suburban populations of Riga did not have the same level of protection as the inner-city population. For example, the suburbs of Riga were destroyed ahead of sieges three times during the 16th – 18th centuries, in order to minimise the prospect of shelter and food for the invading armies. The frequent conflicts also resulted in several famines and plague epidemics, which affected the whole region (Dunsdorfs, 1962). The famine of the winter 1601-2 was particularly severe, leading to people from rural areas in the Vidzeme region to come to the city in search for food. A chronicle written at the time suggests that the city built a shelter for these immigrants and provided food. Despite this help, many died upon arrival, and others died from cold and exhaustion later (Napiersky, 1890). Many of the dead are believed to have been buried in St Gertrude's cemetery (Actiņš et al., 2009, Pīrangs, 1932, Rusovs, 1926).

2. Materials

In total, 721 individuals were excavated from the St Gertrude's cemetery, and 285 of them were non-adults (0-17 years old). There were 190 children in the general cemetery, 55 in the south-western mass grave (MG1) and 40 in the north-eastern mass grave (MG2). Less than 10% of children buried in the mass graves were prematurely born, compared to almost 20% in the GC; likewise, while 40% of children in the GC were aged between one and six years, only half as many individuals of a similar age were found in mass graves (Petersone-Gordina et al., 2018).

Previously acquired adult carbon and nitrogen isotope values were used for comparative purposes for the non-adult population analysed here (Table 1) (Petersone-Gordina et al., 2018). All adult mean isotope data are presented with two standard deviations (sd) throughout this paper.

Table 1. Mean, minimum and maximum adult δ^{13}C (‰VPDB) and δ^{15}N (‰ AIR) values.

Context	**N**	**δ^{15}N ‰**	**2sd**	**δ^{15}N range ‰**		**δ^{13}C ‰**	**2sd**	**δ^{13}C range ‰**	
				Min	Max			Min	Max
GC	51	11.1	2.2	8.7	13.7	-20.4	1.1	-21.2	-18.9
MG1	22	11.2	1.6	9.4	12.5	-20.3	0.9	-21.0	-19.3
MG2	23	11.0	1.5	9.4	12.1	-20.4	0.8	-21.3	-19.3

3. Methods

Individuals for dentine incremental collagen isotope analysis were selected according to age, whereby upper or lower permanent canines had at least 1/3 of their roots present, or the apex of the root was still open (between seven and 14.5 years, according to AlQahtani et al. (2010)), and by the preservation of the tooth – only individuals with post-mortem damage, where the tooth was loose or could be removed without any damage to the alveolar bone, were selected.

Twelve non-adult individuals from the two mass graves (six from each) matched the selection criteria. There were only five individuals from the general cemetery with at least one permanent canine meeting the requirements for this study; to increase the sample size, a lower second incisor and a lower second premolar from two individuals of a similar age were also selected from this context (Table 2).

There was no, or very little, dental wear on the selected teeth, resulting in fully preserved dentine starting from the first increment. Each dentinal increment was assigned an approximate age following the method of Beaumont and Montgomery (2015).
The teeth were prepared for collagen extraction as described by Beaumont et al. (2013 - from Kirsanow et al. 2008), using Method 2. Collagen samples of approximately 0.4 mg were weighed into tin capsules and measured in duplicate using a Costech Elemental Analyser (ECS 4010) connected to a Thermo Scientific Delta V Advantage isotope ratio mass spectrometer. Duplicates are analysed in the same run. Carbon isotope ratios are corrected for ^{17}O contribution and reported in standard delta (δ) notation in per mil (‰) relative to Vienna Pee Dee Belemnite (VPDB). Isotopic accuracy is monitored through routine analyses of in-house standards, which were stringently calibrated against international standards (e.g., USGS 40, USGS 24, IAEA 600, IAEA CH3, IAEA CH7, IAEA N1, IAEA N2): this provides a total linear range in δ^{13}C between -46‰ and +3‰, and between -4.5‰ and +20.4‰ for δ^{15}N.

Analytical uncertainty in $\delta^{13}C$ and $\delta^{15}N$ is typically ±0.1‰ or better for replicate analyses of the international standards and <0.2‰ for replicate sample analysis. The charts show an error bar at 0.2‰. Total organic carbon and nitrogen was obtained as part of the isotopic analysis using an internal standard (glutamic acid, C = 40.82%, N = 9.52%).

For comparison of values, 2sd of the analytical uncertainty (±0.4‰) was used.

Table 2. Selected individuals, their age at death, tooth sample, number of increments, the duration of increment formation for each tooth, and the age of initial crown formation (C_i) (after AlQahtani et al., 2010).

Individual	Age (years)	Sample	Number of samples	Duration of increment formation in years	C_i
			GC		
12	13-14	U3	12	1.2	0.6
41	14-15	L3	14	1.1	0.9
63	7-8	L1	8	1.0	0.6
85	12-13	L5	9	1.3	2.5
134	13-14	U3	11	1.3	0.6
283	8-9*	L3	10	0.8	0.9
615	10-11	L3	13	0.8	0.9
			MG1		
83	10-11	U3	9	1.2	0.6
127	11-12	U3	11	1.1	0.6
156	9-10	U3	11	0.9	0.6
497	13-14	U3	16	0.8	0.6
627	10-11	L3	14	0.7	0.9
630	11-12	L3	16	0.7	0.9
			MG2		
103	10-11	U3	13	0.8	0.6
177	10-11	U3	14	0.8	0.6
432	10-11	U3	10	1.1	0.6
508	8-9	L3	7	1.3	0.9
516	10-11	L3	13	0.8	0.9
606	10-11	L3	14	0.7	0.9

L-lower; U-upper; 3-canine; 1-first incisor; 5-second premolar

4. Results

All resulting collagen samples were above 0.5mg before measuring, and generated C:N atomic ratios between 3.1 and 3.4, thus indicating that the collagen was pristine (DeNiro, 1985, van Klinken, 1999). Collagen yields for each tooth were above 15%. Detailed results of the isotope analysis can be found in Table S5.4 (Supplementary Material S5). The resulting number of increments, and duration of their formation, are shown in Table 2.

Non-adult mean incremental $\delta^{13}C$ values ranged from -21.1‰ (GC134) to -19.2‰ (MG2_103), and mean $\delta^{15}N$ values from 10.1‰ (MG1_156) to 13.5‰ (MG2_103), revealing high individual, rather than inter-contextual, variability (Figure 2; Table 3). Mean incremental dentine and adult bone $\delta^{13}C$ and $\delta^{15}N$ values of individuals from all contexts overlapped within two standard deviations.

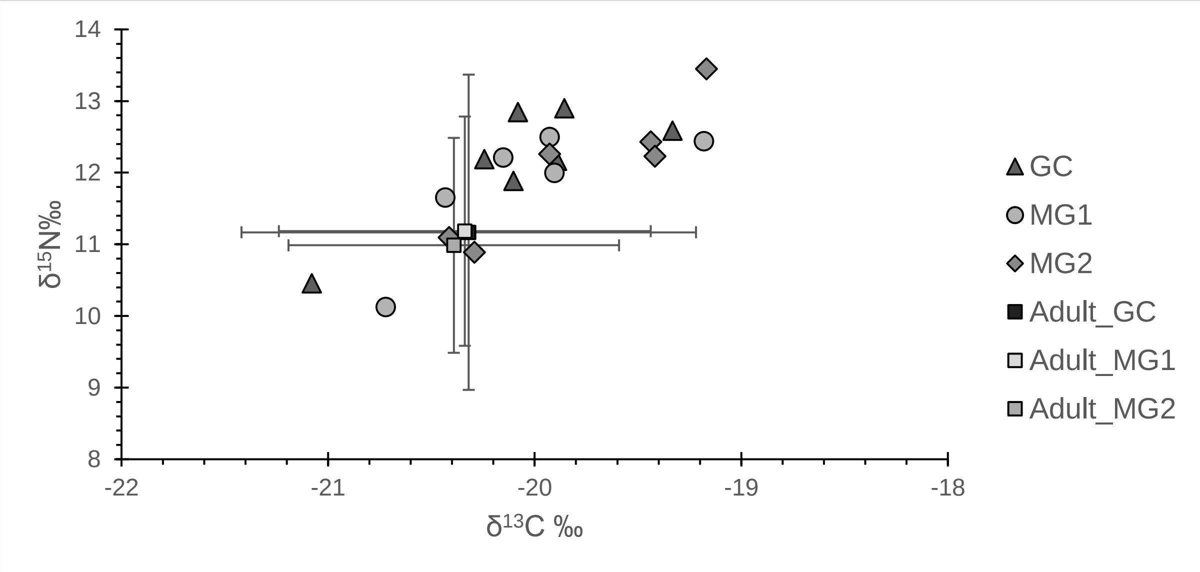

Figure 2. Mean incremental dentine, and adult bone $\delta^{13}C$ and $\delta^{15}N$ values (+/-2sd); GC - general cemetery; MG – mass grave.

Table 3. Mean incremental $\delta^{13}C$ and $\delta^{15}N$ values, ±2sd.

Ind.	$\delta^{13}C$ ‰	2sd	$\delta^{13}C$ range ‰		$\delta^{15}N$‰	2sd	$\delta^{15}N$ range	
			Min	Max			Min	Max
GC								
12	-19.3	0.7	-19.8	-19.1	12.6	0.8	11.9	13.5
41	-19.9	0.6	-20.5	-19.4	12.2	2.1	10.8	14.0
63	-20.1	0.3	-20.3	-19.9	12.8	1.5	12.0	14.4
85	-20.2	0.5	-20.6	-19.9	12.2	0.7	11.6	12.6
134	-21.1	0.5	-21.2	-20.8	10.5	1.0	9.7	11.6
283	-20.1	0.2	-20.3	-20.1	11.9	0.5	11.4	12.2
615	-19.9	0.5	-20.2	-19.4	12.9	2.9	11.2	15.9
MG1								
83	-20.4	1.1	-21.2	-19.8	11.7	0.7	11.1	12.0
127	-19.2	0.4	-19.5	-18.9	12.4	0.7	11.6	12.9
156	-20.7	0.6	-21.1	-20.2	10.1	1.1	9.2	11.5
497	-19.9	0.3	-20.2	-19.7	12.0	1.5	11.0	14.3
627	-19.9	0.8	-20.4	-19.2	12.5	1.0	11.4	13.5
630	-20.2	0.7	-20.9	-19.7	12.2	1.7	11.5	15.1
MG2								
103	-19.9	0.7	-20.5	-19.5	12.3	2.8	11.2	16.0
177	-19.4	0.2	-19.6	-19.2	12.4	0.7	11.9	13.3
432	-19.4	0.3	-19.6	-19.1	12.2	1.4	10.9	12.9
508	-19.2	0.6	-19.6	-18.8	13.4	1.5	12.8	15.0
516	-20.4	0.9	-20.9	-19.6	11.1	0.8	10.2	11.6
606	-20.3	1.0	-20.9	-19.6	10.9	0.8	10.3	11.5

In the GC, variations in $\delta^{13}C$ profiles only exceeded 2sd of analytical error (+/-0.4‰) in GC12, whereby the value decreased by 1‰ between the ages of 4.1 to 6.5 years (Figure 3). Although not exceeding 2sd of analytical error, a progressive decrease in values between the ages of 0.6 and 4.5 years was observed in individuals GC134 and GC615; this might be relevant in the light of a similar, albeit significant, decrease in the $\delta^{15}N$ profiles of both individuals between the same ages (see below). Most of the incremental $\delta^{13}C$ values of GC134 did not overlap with those of other children from this context between the ages of 4.5 and 12.2 years within 2sd of analytical error.

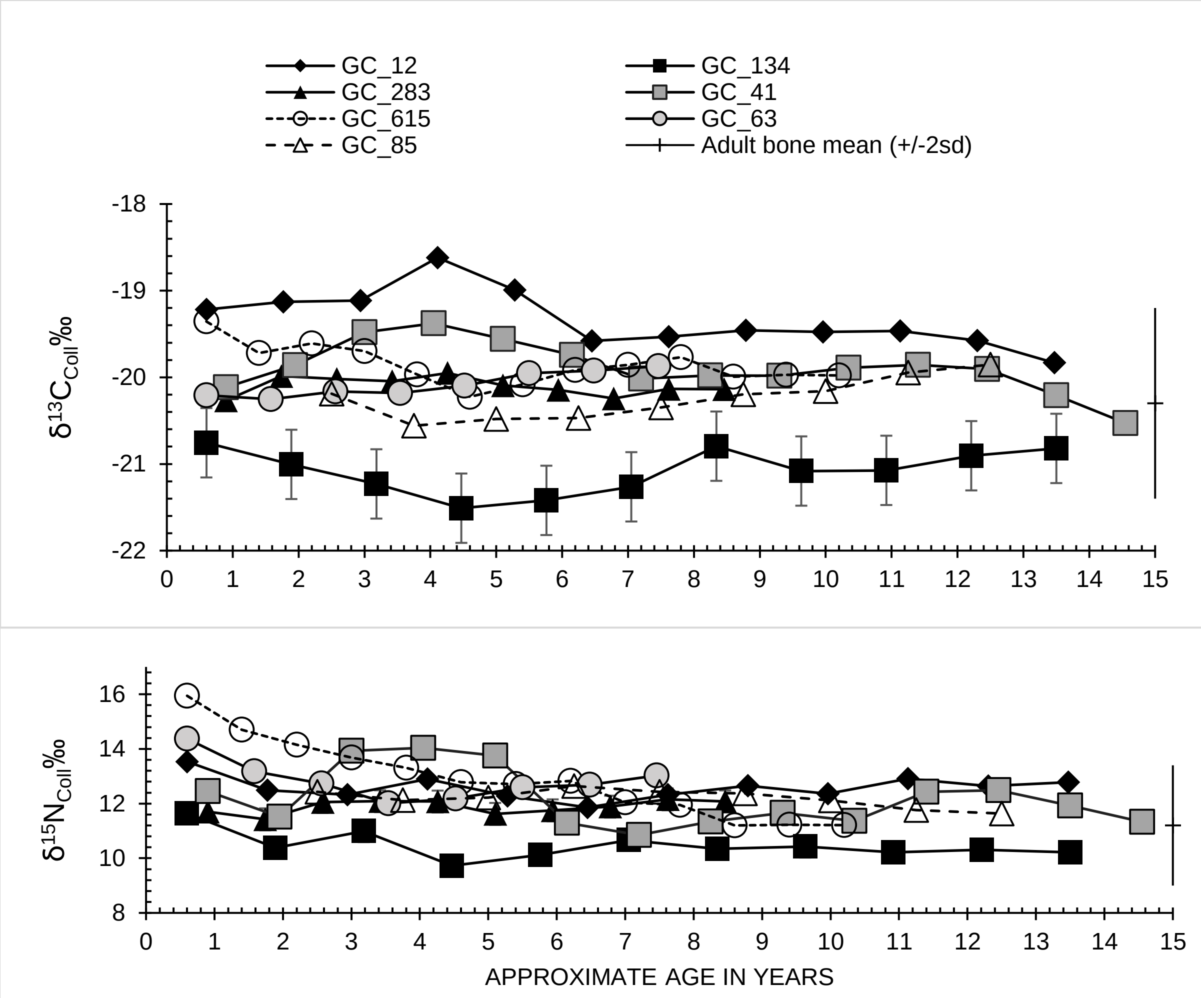

Figure 3. $\delta^{13}C$ and $\delta^{15}N$ profiles of seven individuals from the GC. The profile of GC134 shows 2sd of analytical error for each increment (+/-0.4).

The first $\delta^{15}N$ values of GC63 and GC615 were higher than the adult mean value (11.2+/-2.2‰) (Figure 3). The profiles of both individuals decreased by 2.4‰ and 3.1‰ until the age of 3.5 and 4.6 years, respectively, exceeding 2sd of analytical error. The first period of decrease in GC615 was mimicked by the $\delta^{13}C$ profile.

A progressive decrease in $\delta^{15}N$ values from the first increment onwards, which exceeded 2sd of analytical error, was also observed in individuals GC12 and GC134. In GC12, the value decreased by 1.6‰ until the age of 6.5 years, and the $\delta^{15}N$ profile of GC134 decreased by 1.9‰ until 4.5 years. The initial $\delta^{15}N$ values of GC134 were lower than in other individuals and did not overlap with any other profile (+/-0.4‰) between the ages of 1.9 and 5.8 years (Figure 3).

The $\delta^{15}N$ profile of individual GC_41 increased by 2.4‰ between the ages of 2.0 and 3.0 years (from 11.5‰ to 13.9‰, +/-0.4), and decreased again by 2.9‰ between the ages of 5.1

and 7.2 years (from 13.7‰ to 10.8‰, +/-0.4). Between the ages of 7.2 and 12.5 years, a progressive rise in $\delta^{15}N$ was observed, reaching 12.5‰ at the end of this period. The value decreased again in the last two years of life by 1.2‰, exceeding 2sd of analytical error by 0.4‰. These changes were mirrored by the $\delta^{13}C$ profile, albeit without exceeding 2sd of analytical error. The covariation of both profiles was significant ($r=0.7$; $r^2=0.5$; $p=0.004$; $df=12$; $t=3,43$) (Figure 4).

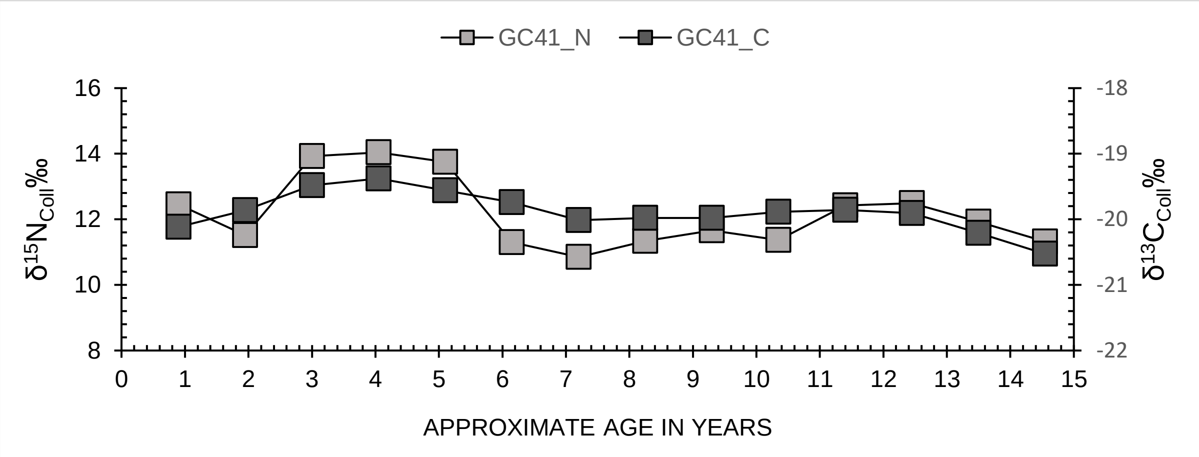

Figure 4. $\delta^{13}C$ and $\delta^{15}N$ values against age in individual GC_41, showing significant covariation.

In three of six children from MG1, variation in $\delta^{13}C$ profiles exceeded 2sd of analytical error. In MG1_83, a progressive rise was observed throughout their whole life, from -21.2‰ at 0.6, to -19.8‰ at 10.2 years of age. $\delta^{13}C$ profile of MG1_630 showed a pronounced decrease in the first three increments, between 0.9 and 2.3 years of age, whereby the values changed by 1.1‰. This was regarded as significant in the light of similar changes in $\delta^{15}N$ profile. Despite the lack of significant changes, the profile of MG1_127 was higher than those of other children, exceeding 2sd of analytical error in the second and the last increments.

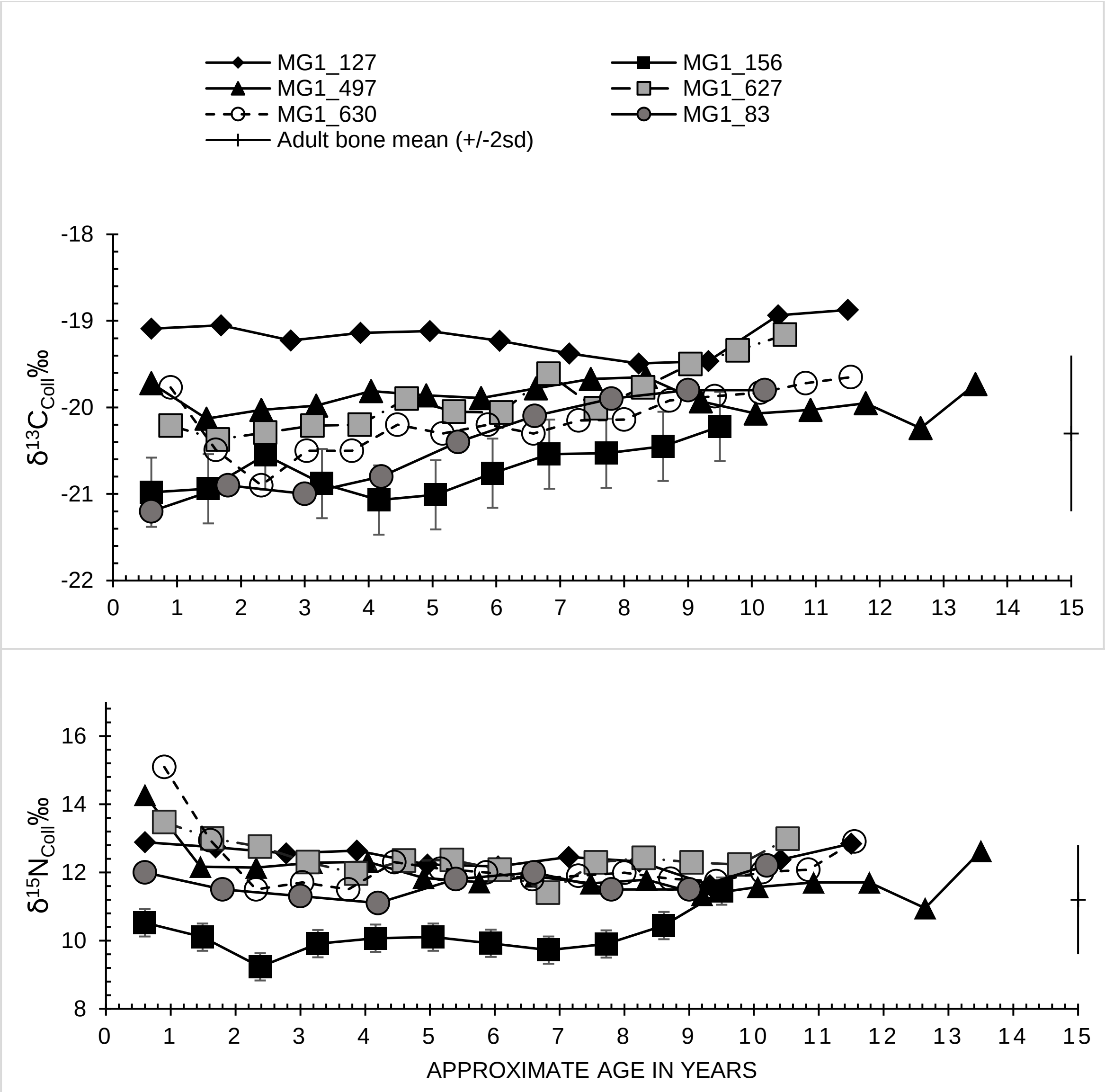

Figure 5. $\delta^{13}C$ and $\delta^{15}N$ profiles of six individuals from MG1. The profile of MG1_156 shows 2sd of measurement error for each increment (+/-0.4).

In individuals MG1_497, MG1_627 and MG1_630, the first incremental $\delta^{15}N$ values were above the mean adult bone value (11.2+/-1.6‰), but the rest of their profiles were consistent with it (Figure 5). In MG1_497, the value dropped by 2.1‰ between the ages of 0.6 and 1.5 years, after which the profile remained stable until shortly before death, when an increase by 1.6‰ was observed between the last two increments (12.6 and 13.5 years of age). In individual MG1_627, a continuous decrease by 1.5‰ was observed between the first and the fifth increment, and ages of 0.9 and 3.9 years. The first $\delta^{15}N$ value of MG1_630 was the highest in this context at 15.1‰ and dropped by 3.6‰ in the two following increments, until the age of 2.3 years. After the drop, no significant changes were observed until the age of 9.4 years, when the value increased by 1.2‰ in four consecutive increments until the person's age at death at 11.5 years. In MG1_127, there was a rise in the last three increments by 1.2‰ between the age of 9.3 years and 11.5 years. The $\delta^{15}N$ profile of MG1_156 remained lower than those of other individuals, exceeding analytical uncertainty in all increments, except the last. In the first three increments, representing the ages of 0.6 and 2.5 years, the value decreased by 1.3‰. This was followed by a long period of insignificant changes until the age of 6.8 years, when a progressive increase by 1.8‰ was observed until the person's age at death at 9.5 years.

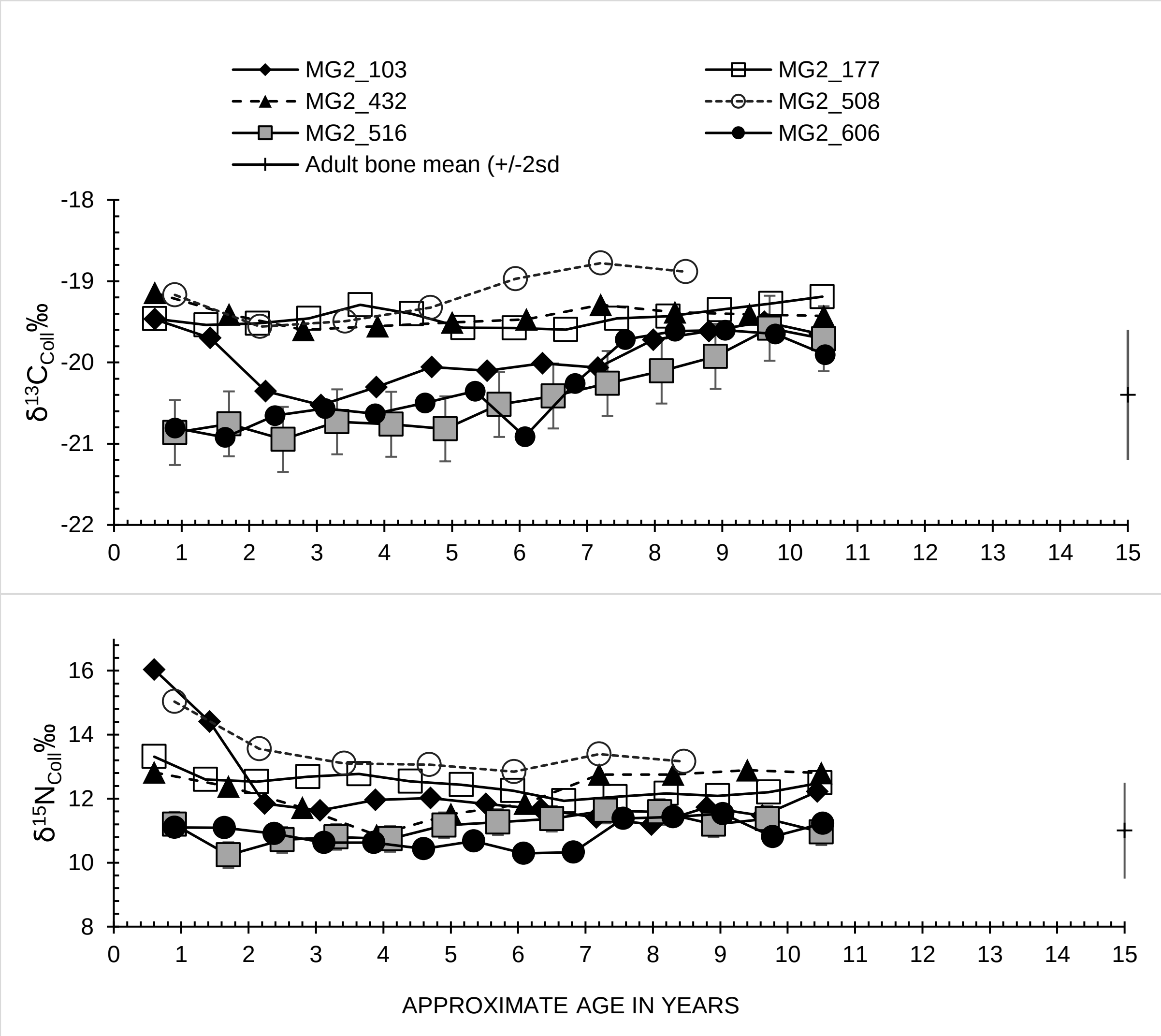

Figure 6. $\delta^{13}C$ and $\delta^{15}N$ profiles of six individuals from MG2. The profile of MG1_516 shows 2sd of analytical error for each increment (+/-0.4).

The $\delta^{13}C$ values of MG2_508 rose above the adult mean value (-20.4+/-0.8‰) at 5.8 years of age and remained so until death at 8.5 years (Figure 6). The $\delta^{13}C$ profiles of individuals MG2_177 and MG2_432 resembled that of MG1_127 in terms of insignificant changes, and similarly high $\delta^{13}C$ values. In MG2_103, $\delta^{13}C$ value decreased by 1‰ between 0.6 and 3.1 years of age. This was mirrored by the $\delta^{15}N$ profile (see below). The value then progressively increased in the second to last increment at 9.6 years of age (-19.5‰), reaching the highest point and the same value as found at 0.6 years.

The profiles of MG2_516 and MG2_606 had lower $\delta^{13}C$ values than those for most other children, except MG2_103, exceeding 2sd of analytical error from 0.9 to around six years of age in both individuals. In MG2_516, the $\delta^{13}C$ value progressively increased by 1.2‰ between the ages of 4.9 and 9.7 years, until the second to last increment. This change exceeded 2sd of analytical error and was similar to the profile of MG1_83, discussed above. In MG2_606, after a period of insignificant changes between 0.9 and 5.3 years, the value increased by 1.2‰ in two consecutive increments until 7.6 years, and this was mirrored by a rise in $\delta^{15}N$ values. In both, MG2_516 and MG2_606, after the period of increase in values, the profiles overlapped with those of other children within 2sd of analytical error.

The $\delta^{15}N$ profile of MG2_508 only overlapped with the adult value (11.0+/-1.5‰) at the age of 5.9 years but remained higher for all other increments (Figure 6), consistent with the child's higher $\delta^{13}C$ profile. The $\delta^{15}N$ value decreased by 1.9‰ in the first three increments representing the ages between 0.9 and 3.4 years. The first $\delta^{15}N$ value of MG2_103 was the highest in this context. In the three following increments, it dropped by 4.4‰, and remained without significant changes throughout the rest of this child's life, regardless of the continuous rise of the $\delta^{13}C$ profile after this age. The profile reached adult mean bone value between the ages of 1.4 and 2.2 years. In MG2_432, the $\delta^{15}N$ value decreased by 1.9‰ between 0.6 and 3.9 years, and then increased again until the age of 7.2 years, reaching the first incremental value. The changes exceeded 2sd of analytical error and were not consistent with the flat $\delta^{13}C$ profile of this individual. In MG2_516, the $\delta^{15}N$ value decreased by 1‰ between the first and second increments, and then increased by 1.4‰ by the age of 7.3 years, mirroring the $\delta^{13}C$ profile. Finally, in MG2_606, changes in $\delta^{15}N$ profile also corresponded to those observed in the $\delta^{13}C$ profile, whereby after a period of little variation, the value increased by 1.1‰ between 6.8 and 7.6 years.

5. Discussion

5.1 Interpretation of the observed $\delta^{13}C$ and $\delta^{15}N$ values

The observed mean non-adult $\delta^{13}C$ values (between -19‰ and -21‰) indicate a mainly terrestrial diet based on C_3 plants, with some marine input for most individuals. This is based on previous studies of mean $\delta^{13}C$ values in C_3 plants (Bender, 1968, O'Leary, 1988) and marine resources (Chisholm et al., 1982, Tauber, 1981, Wada et al., 1993), and their relationship with the consumer (Ambrose and Norr, 1993, Schwarcz and Schoeninger, 1991, Tauber, 1986, Tieszen et al., 1983). Consequently, it has been calculated that a mixed terrestrial and marine diet in humans will yield $\delta^{13}C$ values between -12‰ (purely marine) and -20.0‰ (purely terrestrial) (Schwarcz and Schoeninger, 1991). $\delta^{13}C$ values correlate with salinity, which could cause the end value of a marine component in the diet of past people around the Baltic Sea to be as low as -15‰ if the source mainly derived from the Baltic Sea (Lidén and Nelson, 1994, Strain and Tan, 1979). This is because the salinity of the Baltic Sea can range between 7‰ and 25‰, compared to 35‰ in the oceans (Westman et al., 1999; Robson et al., 2016). Previous research has shown that most archaeological marine fish $\delta^{13}C$ values from the Baltic Sea range between -7.8‰ and -16.6‰ (Robson et al., 2016; Antanaitis-Jacobs et al., 2009). Eastern Baltic cod (*G. Morhua Callarias*), however, has yielded values as high as -18.6‰, with clear differences in both $\delta^{13}C$ and $\delta^{15}N$ values, compared to marine fish from the Western Baltic Sea, as well as the Atlantic Ocean and the North Sea (Barrett et al., 2011; Orton et al., 2011). This has been explained not only by the lower salinity of the Eastern Baltic Sea, but also the limited natural movement of cod between different regions of the sea (ibid; Bagge et al., 1994). Accordingly, the variation in isotope values of marine fish from the Baltic sea might have implications for human dietary isotope values, depending on what fish species dominated their diet.

Mean $\delta^{15}N$ values in the non-adult individuals studied here were between 10.2‰ and 13.1‰, but there are several factors, apart from diet, which might have influenced them. Stable nitrogen isotope values in plant and animal tissue vary depending on their trophic level. Starting at 0‰, the value has been said to be enriched by 3‰ in each successive level (Minagawa and Wada, 1984, Schoeninger and DeNiro, 1984), but more recent research suggests an enrichment by 3-6‰ per trophic level in humans, with the value depending on various factors, including potentially differential enrichment in animals and humans, the composition of the diet, manuring of crops, and individual metabolism (Bogaard et al., 2007, Haubert et al., 2005, Hedges and Reynard, 2007).

In humans, more positive $\delta^{15}N$ values are generally more consistent with a higher percentage of animal protein in the diet (Ambrose et al., 2003, O'Connell and Hedges, 1999). On the other hand, increase in $\delta^{15}N$ values is also associated with physiological and nutritional stress, including rapid growth, illness, or malnutrition, whereby the body uses its own nitrogen reserves (Fuller et al., 2004, Gannes et al., 1997, Hobson et al., 1993, Hobson and Clark, 1992, Kalhan, 2000, Katzenberg and Lovell, 1999, Mekota et al., 2006) and in infants who are being breastfed (Fogel et al., 1989, Fuller et al., 2006). Decreasing $\delta^{15}N$ values have been associated not only with a trophic level shift, but also with growth and development, whereby less nitrogen is excreted from the body than is taken in (Hobson and Clark, 1992, Waters-Rist and Katzenberg, 2010). To distinguish physiological changes from dietary shift, both $\delta^{13}C$ and $\delta^{15}N$ profiles, must be studied together. For example, incremental dentine analysis in children who had survived the Great Irish Famine showed that $\delta^{13}C$ values were a good indicator of dietary shift, while the $\delta^{15}N$ profiles seemed to record both dietary shifts and periods of nutritional stress; consequently, a rise in $\delta^{15}N$ values, without a corresponding rise in $\delta^{13}C$ values, was interpreted as nutritional stress, rather than a change in diet (Beaumont and Montgomery, 2016).

The overlapping of mean $\delta^{13}C$ and $\delta^{15}N$ dentine values in children from all three contexts with those of mean adult bone values were consistent with previous research and suggests that there are no significant dietary differences between the contexts, in terms of access to resources. Individual profiles of children, however, varied within each context, and will be discussed in detail below, to explore similarities and differences between those who were buried in each mass grave and the general cemetery.

5.2 Similarities and differences in dietary profiles within each burial context

5.2.1 The general cemetery

In the GC, the $\delta^{13}C$ profiles were relatively flat, indicating little change in diet throughout childhood in most individuals, except GC12, whereby the decrease in both values indicates a reduction in marine resources between the ages of four and six-and-a-half years. The lower $\delta^{13}C$ and $\delta^{15}N$ values of individual GC134 indicate a diet with less marine input than in other children from this context and might suggest that the child either lived in an area where marine fish were not available, or had different dietary preferences, while living in the same community. The changes in $\delta^{13}C$ and $\delta^{15}N$ profiles of GC41 were unlike any other individual in the cemetery. The sudden increase and decrease in both values, especially $\delta^{15}N$ between two and seven years of age, might indicate an increase in the marine proportion of the diet, although a period of nutritional stress cannot be excluded, since the changes in $\delta^{13}C$ profile were not significant. It is possible that the differences in diet observed up to the age of seven years in this child, compared to the other children from the GC, might be due to a different origin, and this possibility will be explored further by strontium isotope analysis. The similarity of the rest of the profile with those of other children from the GC, however, suggests that by the time of death, the child had been a resident of Riga, or indeed Gertrude village, for at least seven years.

5.2.2 The mass graves

The profiles of most children in both mass graves showed greater variation and are difficult to interpret in terms of the presence of different population groups. Two profiles, however, stood out as different. The lower $\delta^{15}N$ profile of MG1_156 indicates a lower proportion of terrestrial animal and/or marine protein in the diet. On the other hand, all $\delta^{15}N$ values of this individual remained within the adult mean, and thus might represent individual dietary variation. Likewise, the higher $\delta^{13}C$ and $\delta^{15}N$ profiles of MG2_508, compared to the adult mean, might not be significant in the light of overlapping values with several other children from this context.

The results showed that the $\delta^{13}C$ values of MG1_103 and MG2_630, and MG1_83 and MG2_516 changed in the same way from the first to the last increments. Likewise, the profiles of MG1_127, MG2_177 and MG2_432 were also similar (Figure 7). Since $\delta^{13}C$ is a good indicator of diet and is not influenced by physiological processes to the same extent as $\delta^{15}N$, as discussed above, the profile patterns suggest similar diets for these groups of individuals. This, in turn, points to the probability that both mass graves contained some children from the same communities.

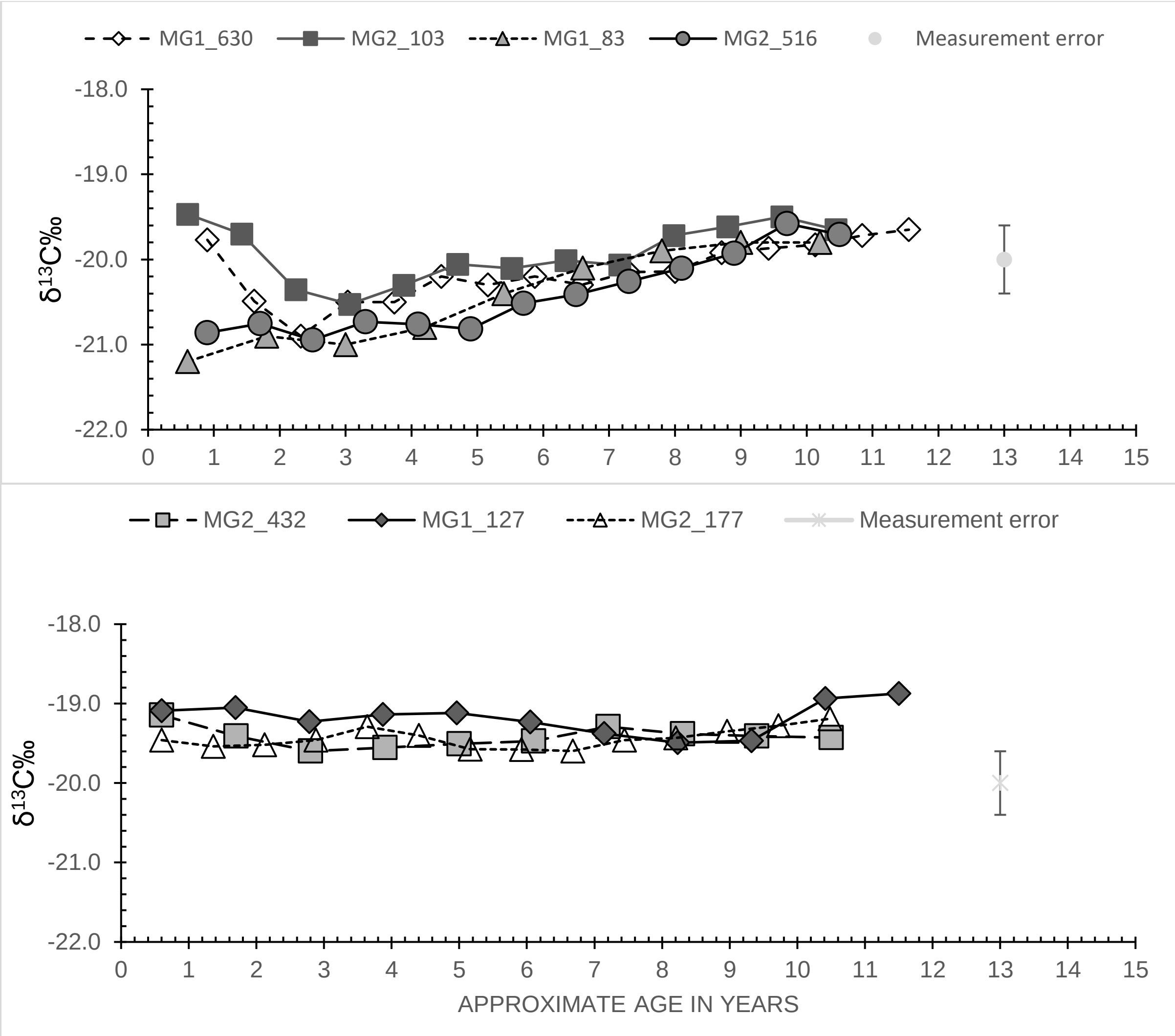

Figure 7. Similar δ^{13}C profiles in groups of individuals from both mass graves.

So far, there is no evidence for similar δ^{13}C profiles for children who were buried in either of the mass graves and the GC. This partly supports the first hypothesis, that there would be detectable differences in incremental dentine profiles of individuals from Riga and other regions. This suggests that while people living in Riga and rural areas along the coastline, or with good trade links to the coastline, had access to similar resources, they were used differentially in each community, or even each family, based on the substantial differences in individual profiles in all contexts, and mass graves in particular.

5.3 Immigrants to Riga during the famine of 1601-2

Four of the six children from MG1 (MG1_127, MG1_156, MG1_497 and MG1_630) showed an increase in their δ^{15}N values before death, without corresponding changes in δ^{13}C values.

The rise occurred after a period of relative stability in the profiles of all four individuals, and the changes appear to be representative of a collective experience which took place at the same time, given that these individuals likely died within days, or weeks, of each other. It is therefore possible that MG1 contains victims of the famine of 1601-2.

Similar changes in $\delta^{15}N$ values have been reported in individuals from other cemetery populations who are known to have experienced nutritional stress, including the victims of the Great Irish Famine in Ireland (mid-19th century AD) (Beaumont and Montgomery, 2016, Beaumont et al., 2015), and people living in the Neolithic period on the Shetland Islands of Scotland (Montgomery et al., 2013). However, the absence of increase in $\delta^{15}N$ values in the other two individuals from MG1 does not mean that the famine did not affect them; The facilities provided for the immigrants, as discussed in Section 1.1 above, might have provided adequate nutrition, especially for those who arrived early and only experienced a brief, if any, period of undernutrition. The shelter and food, however, did not necessarily protect them from the cold and infections such as typhus and dysentery, which occur in overcrowded, unhygienic environments, and are exacerbated by weakened immune system (Dirks et al., 1980, WHO, 2002). A rapid death from infection in children who received adequate nutrition throughout the famine would therefore not leave any trace of nutritional stress in their isotopic profiles.

None of the $\delta^{15}N$ profiles of children from MG2 exhibited changes towards the end of their lives. This is consistent with rapid death, probably due to an epidemic. As discussed in Section 1.1, there were two plague epidemics in the 17th century, in 1601, and in 1623. It is possible that people from rural areas came to Riga not only during the famine of 1601-2, but also as a result of other hardships. This is supported by historical sources which state that, for many, the main reason for coming to the city was the prospect of a burial, because this was no longer possible in their homes due to the scarcity of a population to carry that out (Napiersky, 1890). This would explain the presence of children from the same communities in both mass graves, if their deaths relate to two different historical events.

5.4 The origin of the children in mass graves

The variation in individual dietary profiles of children from the mass graves, as opposed to more similar, flat, patterns observed in the GC, points to the possibility that the children from the mass graves represent different communities, while most of those buried in the GC were from Gertrude village, or its vicinity. The lack of comparative evidence from other rural populations from Latvia, however, makes identification of a typical biological rural profile difficult. Incremental dentine analysis using data from contemporary rural populations would be necessary to develop this argument, and to further explore possible differences in the diet of urban and rural populations, as well as childhood diets in post-medieval Latvia.

As shown by relatively few changes in both, $\delta^{13}C$ and $\delta^{15}N$ profiles of children from the GC, these individuals represent a population group with mostly constant access to food resources, although the cemetery was in use for over three hundred years. Children from each mass grave, however, represent the same generation, albeit one that experienced several hardships during their lifetime, as expressed in evidence for physiological stress very early in the lives of several individuals (see Section 5.5), and at the end of life in four people from MG1. There remains a possibility that changes in diet during hardships could be expressed in different isotopic profiles of the generation who experienced them, even if all the people buried in St Gertrude's cemetery derived from the same, local, population. Moreover, the famine of 1601-2, as well as outbreaks of plague, affected the whole region, including Riga, and some victims were buried in St Gertrude's cemetery, as mentioned in Section 1.1. To further explore the possible origin of the people from the mass graves, a pilot study using strontium isotope analysis, is in progress.

5.5 Differences in the initial $\delta^{15}N$ values and profile patterns

Finally, in all contexts, the first $\delta^{15}N$ values of some children were higher than the adult mean. High initial $\delta^{15}N$ values have been interpreted as a signal of breastfeeding, since breastfed infants are a trophic level (2-3‰) above their mothers or wet-nurses (Fogel et al., 1989, Fuller et al., 2006, Wright and Schwarcz, 1999). Consequently, a drop in $\delta^{15}N$ values has been interpreted as a signal of weaning, whereby the introduction of solid foods causes a negative trophic level shift (Dupras et al., 2001, Eerkens et al., 2011, Fuller et al., 2003, Mays et al., 2002, Richards et al., 2002). All but one tooth analysed in this research began forming before the age of one year, and it is likely that they reflect both the period of exclusive breastfeeding and the period of weaning, as evidence gathered from folklore and ethnographic studies from 19th – early 20th century Latvia suggests that children were not completely weaned until one or two years of age (Muktupāvela, 2005).

Beaumont and co-workers (2015) have recently argued that high $\delta^{15}N$ values have been found in infants too young to have been breastfed at the age of death (Kinaston et al., 2009, Nitsch et al., 2011, Richards et al., 2002), and might therefore represent in-utero $\delta^{15}N$ values, which are influenced by changes in the mother's diet and physiology during pregnancy (Fuller et al., 2004). A high neonatal $\delta^{15}N$ would rise even higher during breastfeeding; conversely, in well-nourished infants with a low $\delta^{15}N$ at birth, the increase during breastfeeding will be small, and might be undetectable using incremental dentine analysis (Beaumont et al., 2015).

To interpret a decrease in initial $\delta^{15}N$ values as a possible signal of weaning, a similar change in $\delta^{13}C$ values should be observed, because a rise of $\delta^{13}C$ values by approximately 1‰ has been reported during breastfeeding (Fuller et al., 2006, Katzenberg et al., 1993, Richards et al., 2002, Wright and Schwarcz, 1999). Consequently, it is possible that the high first incremental $\delta^{15}N$ values of GC63, GC615, MG1_497, MG1_627, MG1_630, and MG2_103 and MG2_508 are consistent with in-utero stress. In individuals GC615, MG1_630 and MG2_103 where both $\delta^{15}N$ and $\delta^{13}C$ profiles decreased in the following increments, the changes might represent weaning. In other individuals, where the $\delta^{15}N$ value decreased without corresponding changes in $\delta^{13}C$, this might be due to growth and development, as discussed above. Weaning and/or growth might also explain initial profiles of individuals in which a decrease in both, or only $\delta^{15}N$ values, was observed at the beginning of life, albeit without $\delta^{15}N$ values exceeding the adult mean.

6. Conclusions

Overall, the results of this research support both hypotheses, which predict the observed similarities of individual profiles of several children from both mass graves, but not between mass graves and the GC, and also the evidence for nutritional stress shortly before death in four individuals from MG1. On the other hand, even though the profiles were different in children from the mass graves and the GC, the mean values of the whole population were similar. This suggests that if there are different population groups buried in St Gertrude's cemetery, as also suggested by earlier findings of inter-contextual differences in dental attrition and dental disease prevalence in adults and children, all of them had access to similar resources, but used them differentially, and probably not only in each community, but in individual family groups.

The small sample size, and the lack of comparative data from other contemporary rural and urban cemetery populations, limits identification of rural immigrants in the cemetery. Accordingly, differences in profiles of children from mass graves might simply represent different dietary strategies during hardships which these children experienced which eventually caused their premature deaths, according to both historical sources and isotopic evidence gathered during this research.

The findings of this research are a new addition to emerging evidence for childhood diet in past populations, using newly developed methods that focus on incremental dentine analysis. It has also identified victims of a historical famine in Latvia, based on changes in $\delta^{15}N$ values towards the end of life for four children from MG1. Studies of known victims of famine are currently very rare (Beaumont and Montgomery, 2016), and thus the data presented here provide a useful reference for future research exploring nutritional stress as expressed in incremental dentine $\delta^{13}C$ and $\delta^{15}N$ profiles.

Acknowledgements

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Chapter 6. Manuscript 3.

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Applying strontium isotope analysis to identify possible rural immigrants buried in the 17th century mass graves of the urban St Gertrude Church cemetery in Riga, Latvia

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Keywords: Migration; Non-adult individuals; post-medieval Eastern Europe; Diet

Abstract

The aim of this study was to identify immigrants from the rural region of Vidzeme buried in two mass graves in the post-medieval St Gertrude Church cemetery in Riga, Latvia, using strontium isotope analysis ($^{87}Sr/^{86}Sr$), and previously acquired carbon ($\delta^{13}C$) isotope dietary profiles produced from incremental dentine analysis. Enamel and dentine samples were taken from 19 non-adult individuals. Animal bones from Riga and rural Vidzeme were also analysed to estimate the local strontium isotope biosphere range. The results confirmed the presence of one clear outlier in the population, and one child who had probably originated from rural Vidzeme. The lack of significant differences in $^{87}Sr/^{86}Sr$ ratios between other individuals from the general cemetery and two mass graves suggested that they were representative of one, local, population. Plotting $^{87}Sr/^{86}Sr$ ratios against mean dentine $\delta^{13}C$ values revealed that several children with similar incremental dentine profiles did derive from the same community. A strongly negative correlation between $^{87}Sr/^{86}Sr$ ratios and mean $\delta^{13}C$ values in people buried in the mass graves, but not the general cemetery, were suggestive of short-term dietary strategies in the same community. Apart from yielding the first comparative strontium isotope ratio data from archaeological skeletons in Latvia, the observed regional differences also suggest that there is potential for future local and regional migration studies.

1. Introduction

The cemetery of St Gertrude Church in Riga, Latvia dates from the 15th – 17th centuries AD and was excavated in the autumn of 2006 in advance of planned building works in the area. The excavation revealed two mass graves along with single burials in the general cemetery (Actiņš et al. 2009). The date of both mass graves coincides with a number of natural disasters affecting the city during the 17th century, including the Polish-Swedish war, a severe famine in the winter of 1601-02, following the beginning of the war and a particularly bad harvest in the previous season, and a plague epidemic (Napiersky, 1890). Historical accounts suggest that the famine forced people from the rural region south-east of Riga to come to the city to seek help, and that many of the immigrants died on the outskirts of the city. It is believed that many were buried in the St Gertrude's cemetery (ibid.). The individuals excavated from this cemetery have provided a unique opportunity to study aspects of the lives of populations in the suburbs of Riga during the post-medieval period, and to add considerably to currently scarce bioarchaeological data from Latvia.

The main aim of this study was to identify possible rural immigrants in one, or both mass graves, and possibly the general cemetery, of St Gertrude Church cemetery, with the help of radiogenic strontium ($^{87}Sr/^{86}Sr$) isotope analysis of the dental enamel of 19 children. Strontium analysis has never been carried out in Latvian skeletal populations, and the results provide the first comparative ratios from the country, as well as revealing if there is future potential for local mobility studies. This study builds on previous research on carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) stable isotope analysis of incremental dentine samples from the same 19 children. Similarities in $\delta^{13}C$ profiles of several children from both mass graves were found, while no similar profile patterns were observed between people buried in the mass graves and the general cemetery. The hypotheses to be tested are:

1) Most individuals in the general cemetery were of local origin, while most of those in the mass graves were immigrants;
2) Children from both mass graves who showed similar incremental dentine $\delta^{13}C$ profiles will also have similar enamel $^{87}Sr/^{86}Sr$ ratios, suggesting that they came from the same geographic region, or even the same communities.

1.1 Strontium isotope analysis

Strontium (Sr) isotopes were first used to study mobility in past human populations in the mid-1980s (Ericson, 1985), and they have become one of the most effective methods to distinguish local and non-local individuals in early prehistory (Bentley et al., 2002, Cox and Sealy, 1997, Montgomery et al., 2000, Müller et al., 2003, Sillen et al., 1998) as well as later periods of history (Montgomery et al., 2005, Scheeres et al., 2013, Shaw et al., 2016). Sr is an alkaline earth metal with three non-radiogenic isotopes (^{84}Sr, ^{86}Sr and ^{88}Sr) and one radiogenic (^{87}Sr) isotope. Each type of rock has distinctly different ^{87}Sr/^{86}Sr ratios, which are released into soil and groundwater by the natural degradation process. From there, Sr isotopes pass largely unmodified through the food chain and into living organisms – plants, animals and humans (Graustein, 1989, Hurst and Davis, 1981, Kawasaki et al., 2002). Due to the similar chemical properties of Sr and calcium (Ca), when taken up by animals and humans with food and water, it substitutes for Ca in bone and enamel apatite (Bentley, 2006, Bentley et al., 2004), from where it can be extracted in archaeological faunal and human remains.

The ^{86}Sr/^{87}Sr ratios of underlying geological formations, however, cannot be used on their own to establish local biosphere values against which to compare the ratios obtained from archaeological human remains found in the same area. Despite the small rate of modification while passing from the rocks into the food chain, there are factors that also influence the isotope ratios in soil. For example, some minerals with high ^{86}Sr/^{87}Sr ratios also weather more slowly, which means that the isotope ratio in the soil is reduced compared to the whole rock (Åberg et al., 1989, Bentley, 2006). Likewise, Sr isotopes in coastal areas have been found to be dominated by seawater Sr rather than the underlying rocks, yielding ^{86}Sr/^{87}Sr ratios closer to that of the seawater, which is currently 0.7092 (McArthur et al., 2001). In the southern Baltic sea, the value can reach as high as 0.7097 (Price et al., 2012). This is because the salinity of the Baltic Sea can range between 7‰ and 25‰, compared to 35‰ in the oceans (Robson et al., 2016, Westman et al., 1999). This sea spray phenomenon has been described in studies from the Hawaiian Islands (Chadwick et al., 1999, Whipkey et al., 2000) and Guatemala (Hodell et al., 2004) in the Americas, and the Outer Hebrides in Scotland (Montgomery, 2006, Montgomery et al., 2003). A further complication is the decrease of ^{86}Sr/^{87}Sr ratios up the food chain. This means that ^{86}Sr/^{87}Sr variation in soil and plants is considerably reduced in animals, which eat a variety of plants in any area, thus averaging the ^{86}Sr/^{87}Sr in the skeletal tissue over time. Several studies have demonstrated a low standard deviation (SD) in ^{86}Sr/^{87}Sr in animal bones, including a comparison of ratios in soil, leaves, caterpillars, snails and birds (Blum et al., 2000), salmon

(Koch et al., 1992) and elephants (Hall-Martin et al., 1993, van der Merwe et al., 1990). Consequently, obtaining $^{86}Sr/^{87}Sr$ ratios from the underlying rocks does not mean that they represent the locally available values of vegetation that grows in the soil, or those found in animals and humans who sourced food in the area.

To obtain $^{87}Sr/^{86}Sr$ ratios for mammals, which can be used to support human migration studies, researchers have compared isotope ratios from various modern and archaeological animal bones and teeth. Most studies have concluded that animals with a narrow roaming range, such as mice, rabbits, and squirrels have the lowest variation in $^{87}Sr/^{86}Sr$ and they therefore can provide a reliable estimate of local $^{87}Sr/^{86}Sr$ (Ezzo et al., 1997, Price et al., 2002).

It also has to be taken into account that archaeological bone is often subject to contamination and degradation during burial, so much so that the groundwater Sr can replace the existing Sr in the mineral portion of the bone (Hoppe et al., 2003, Lee–Thorp, 2002, Nelson et al., 1986). Likewise, dentine has also been proven to undergo diagenetic alteration in burial environment, whereby the biogenic Sr ratio in dentine will gradually become closer to the local soil biosphere ratio, leading to considerable variations between enamel and dentine samples from the same individual (Budd et al., 2000).

The basement under the territory of Latvia is composed of Proterozoic magmatic and metamorphic rocks. The Ediacaran and Palaeozoic sedimentary rocks cover the surface of the crystalline basement, of which Devonian deposits form the uppermost part in almost the whole territory of Latvia (94%); these are generally found at a shallow depth, excluding areas of the eastern Latvian glacial uplands. In the south-west of the country, however, the Devonian rocks are replaced by Carboniferous, Permian, Triassic and Jurassic deposits in an area covering $3800km^2$ (Zelčs and Nartišs, 2014; Lukševičs and Stinkulis, 2018) (Figure 1).

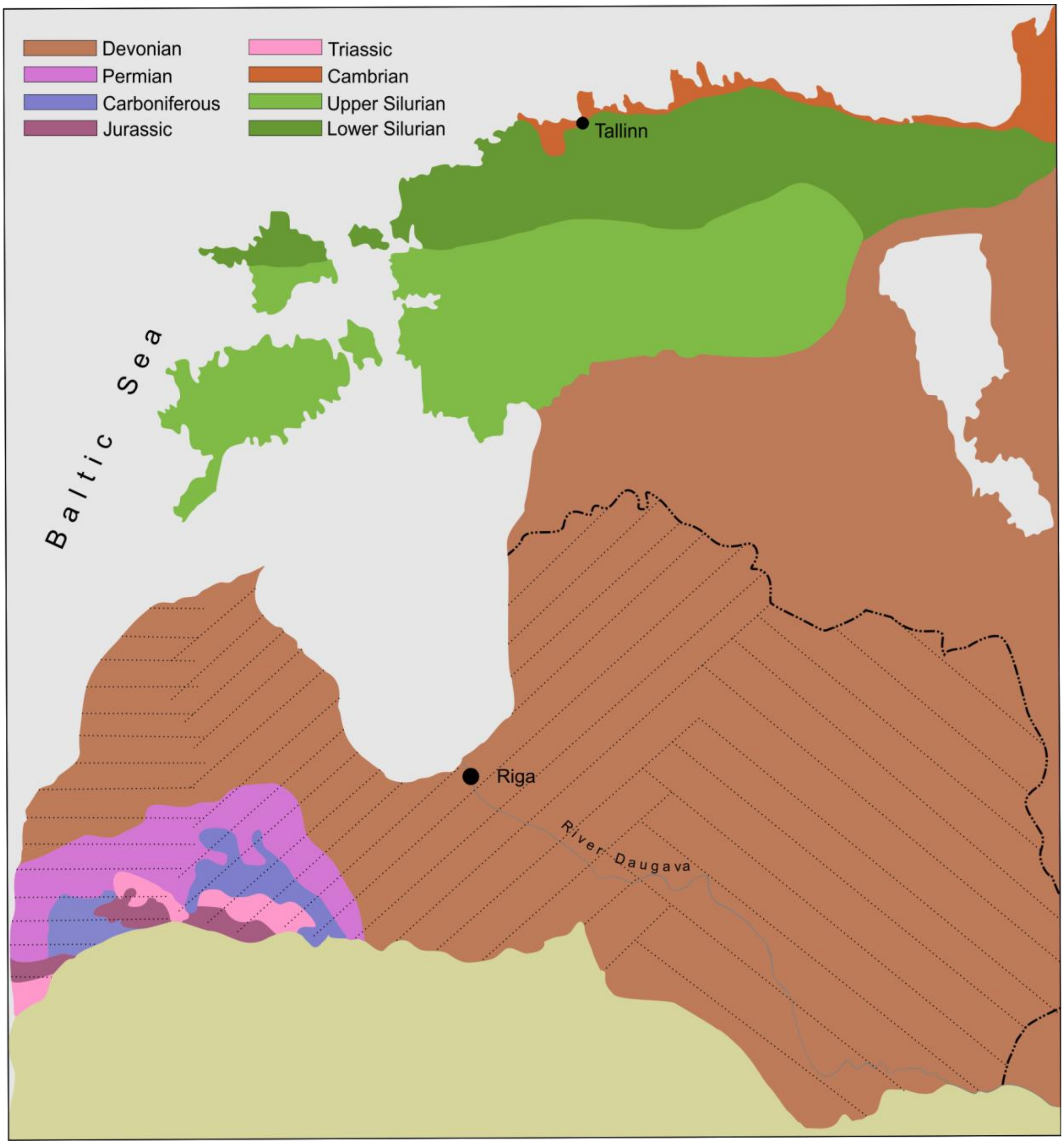

Figure 1. Geological map of Latvia also showing Estonia. The dotted lines highlight approximate boundaries of the three main areas of Quaternary deposits in the territory of Latvia (map combined from Brangulis et al., 1998, Danilans, 1973, Dreimanis, 1939).

The sedimentary rocks only appear in restricted bedrock outcrop areas, such as in river valleys and coastal cliffs along the north-eastern coast of the Gulf of Riga; the rest of the bedrock surface is covered by the Middle and Upper Pleistocene, predominantly glacial, deposits of till, sand and gravel, and silt and clay, with an average depth of 5-20 m in the lowlands and 40-60 m in the uplands. In isolated areas of the highest local topography, particularly in the Vidzeme Upland, a total thickness of the Pleistocene deposits can reach a depth of up to 200 m (Zelcs et al., 2011). The sediments of previous interglacials have mostly been removed as a result successive glacial erosion of the Fennoscandian Ice Sheet, which covered the territory of Latvia four times (Dreimanis and Zelčs, 1995). Although no $^{87}Sr/^{86}Sr$ mapping has been done of Latvian bedrock or soils to date (Gilucis and Segliņš, 2003), it is expected that bioavailable $^{87}Sr/^{86}Sr$ ratios would depend on the composition of the Quaternary deposits, as is also the case in Denmark (Price et al., 2012). These form three main areas in the territory of Latvia, consistent with the direction of ice masses of the Baltic, Riga and Peipsijärv ice streams during the expansion and deglaciation of the last Fennoscandian ice sheet (Dreimanis and Zelčs, 1995). Despite the largely monolithic underlying geology, noticeable variations can be expected between these areas, including Riga and a part of Vidzeme (Figure 1). Since all sampled sites in this research are located in the same area of Quaternary deposits, it is unclear if there will be any differences in Sr ratios between them. The ratios are expected to be dominated by Devonian deposits, which have yielded ratios of 0.7101 and 0.7121 in rocks (Evans et al., 2010) and 0.7113 and 1.7129 in vegetation in Britain (Chenery et al., 2010).

1.2 Historical background

During the 17th century, the city of Riga was one of the major cities of Livonia (Now the south-eastern part of Latvia (locally named Vidzeme), and northern part of Estonia), a region ruled at various times by the Polish-Lithuanian Commonwealth and Germany, but also claimed by Sweden and Russia (Figure 2). The St Gertrude Church of Riga was built outside the city walls and is first mentioned in historical sources in 1413 as the main church that served the people who lived in Gertrude village and its vicinity, as well as patients from the nearby St George's hospital. Likewise, the cemetery around the church mostly accommodated the local people, and those who died at the hospital (Šterns, 1998: 355). Nevertheless, St Gertrude Church cemetery has also been mentioned in historical sources as the final resting place for poor rural immigrants from Vidzeme, who came to Riga for help during the famine of the winter of 1601-2 and lived near the St Gertrude Church and St George's hospital. Despite food being provided by the city, people died in great numbers from cold and exhaustion (Actiņš et al., 2009, Pīrangs, 1932, Rusovs, 1926). The famine of 1601-2 was caused by a poor harvest and exacerbated by the beginning of the Polish-Swedish war (1600-29), with the invading Polish army looting the farmsteads in rural Vidzeme and leaving many peasants with no food supplies. Just after the famine, a plague epidemic in 1602 then affected the same region, including the city of Riga; the city suffered a subsequent plague epidemic in 1623 (Napiersky, 1890).

Figure 2. Map of Latvia, showing sampling sites in rural Vidzeme (Limbazi, Cesis, and Mazstraupe).

The presence of the 17th century mass graves in the St Gertrude's cemetery complements historical evidence about the disasters described above causing mass mortality during this period. With the famine and the plague epidemic in 1601-02 being almost simultaneous, it is possible that the mass graves represent different population groups, including the inhabitants of the city of Riga, the local Gertrude village population, as well as rural immigrants from Vidzeme.

2. Material and methods

During a 2006 excavation, 721 individuals were uncovered from St Gertrude's cemetery, and 286 of them were buried in two mass graves (166 buried in mass grave one (MG1) and 120 in mass grave two (MG2)). In total, there were 285 non-adults (0-17 years old), with 190 children buried in the general cemetery (GC), 55 in MG1 and 40 in MG2. The deceased excavated from the mass graves did not show any evidence for perimortem trauma, and some aspects of the demographic profile, especially with regard to non-adult age groups represented in the cemetery, point to an event that caused catastrophic mortality of the people buried in both mass graves (Gerhards, 2009a, Keckler, 1997, Petersone-Gordina et al., 2018).

Previous results of incremental dentine analysis of the teeth of the selected 19 individuals showed that one individual (GC_41) had a distinctly different $\delta^{13}C$ and $\delta^{15}N$ profile when compared to other children from the general cemetery, or the mass graves, indicating that they might not have been local; likewise, similar $\delta^{13}C$ profile patterns were observed in MG1_630 and MG2_103, MG1_83 and MG2_516, with another pattern shared by MG1_127, MG1_177 and MG2_432, suggesting that these individuals might have derived from the same communities based on their diet, as reflected in their $\delta^{13}C$ values; unlike $\delta^{15}N$, $\delta^{13}C$ isotope values in humans are less subject to changes due to physiological processes, and are thus believed to be mainly influenced by diet (Beaumont and Montgomery, 2016, Hedges and Reynard, 2007); hence, similarities in $\delta^{13}C$ profiles can be interpreted as evidence for similarities in diet. Furthermore, a child from MG1 (MG1_156) had a lower $\delta^{13}C$ and $\delta^{15}N$ profile compared to other children, which was explained as being the result of either individual dietary variation, or the possibility that they had also come to Riga from elsewhere. To explore the origin and/or dietary differences of these individuals, $^{87}Sr/^{86}Sr$ isotope ratios were obtained for comparison with the previously obtained mean $\delta^{13}C$ values (Table 1) (Petersone-Gordina et al., Forthcoming (a)).

Age at death and sex in this population has been estimated previously, and a detailed demographic profile of the populations has been published (Petersone-Gordina et al., 2018). For this analysis, age estimation in all children was based on tooth formation and eruption stages (AlQahtani et al., 2010). Since both, incremental dentine and Sr isotope analyses were to be performed using the same teeth, only non-adult individuals were considered for sampling. Selection criteria have been described previously (Petersone-Gordina et al., Forthcoming (a)). Six children were selected from each mass grave, and seven from the GC. Apart from enamel, crown dentine samples from four individuals were also included in the analysis to monitor the diagenetic shift in the dentine towards labile strontium in the burial soil (Montgomery et al., 2007). This is because, unlike enamel, dentine absorbs Sr from burial soil, thus altering its biogenic composition, which is identical to the composition of enamel in living individuals (Montgomery, 2002, Tsalev, 1984), as well as in archaeological individuals recovered from environments other than burials in soil (Montgomery et al., 2007).

Because the site is now in the centre of the city, obtaining modern small animal remains, which have been proven to be very good for establishing local biologically available $^{87}Sr/^{86}Sr$ isotope ratios (Price et al., 2002), was not possible. Neither were there any archaeological animal remains available from the St Gertrude's cemetery. Instead, to obtain a reference for the local $^{87}Sr/^{86}Sr$ soil biosphere of Riga, four animal bone samples from broadly contemporary cemetery sites in the inner city of Riga were analysed (Figure 3). It was also possible to analyse faunal samples from medieval cemeteries in Cesis, Limbazi, and Mazstraupe, located in rural Vidzeme (for map, see Figure 2; for all sample details, see Table 2). All faunal samples were selected subject to availability and preservation, rather than with specific locations in mind.

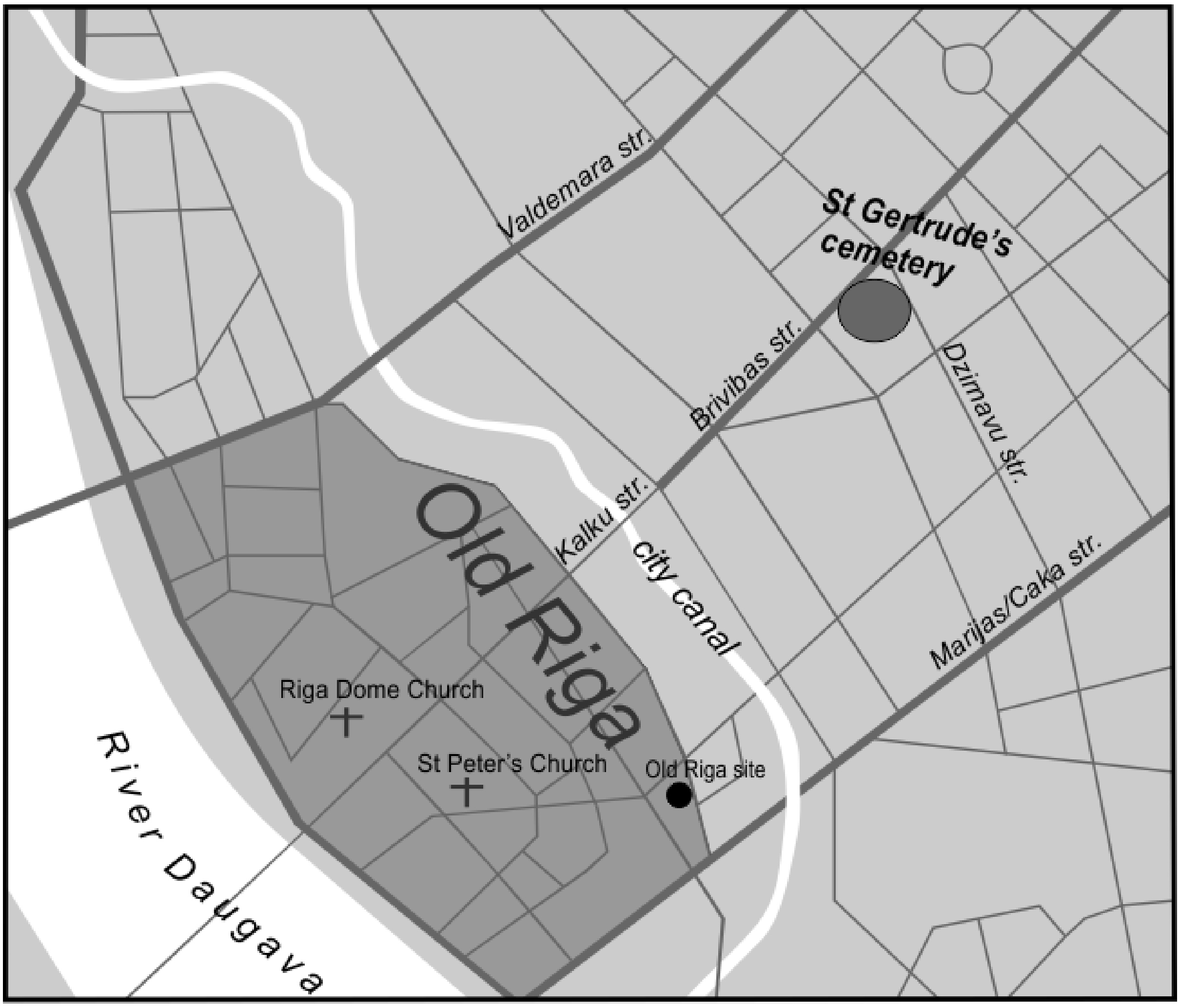

Figure 3. Map of Riga, showing the location of St Gertrude's cemetery, Riga Dome and St Peter's churches, and the third site in old Riga from which a faunal sample was collected.

The obtained $^{87}Sr/^{86}Sr$ ratios from enamel, dentine and animal bone samples were compared using a Kruskal-Wallis test for more than two groups, and a non-directional Mann-Whitney test for two groups, with α level at 0.05. If any of the tested groups was smaller than five, significance was determined by using a standard table of Mann-Whitney critical values, as the p value could not be calculated.

Table 1. Previously acquired mean $\delta^{13}C$ and $\delta^{15}N$ values from incremental dentine analysis (from Petersone-Gordina et al., Forthcoming (a)).

Individual	Mean $\delta^{13}C$‰ VPDB	Mean $\delta^{15}N$‰ AIR
GC_12	-19.3	12.5
GC_41	-19.9	12.2
GC_63	-20.1	12.8
GC_85	-20.2	12.2
GC_134	-21.1	10.5
GC_283	-20.1	11.9
GC_615	-19.9	12.9
MG1_83	-20.4	11.7
MG1_127	-19.2	12.4
MG1_156	-20.7	10.1
MG1_497	-19.9	12.0
MG1_627	-19.9	12.5
MG1_630	-20.2	12.2
MG2_103	-19.9	12.3
MG2_177	-19.4	12.4
MG2_432	-19.4	12.2
MG2_508	-19.2	13.4
MG2_516	-20.4	11.1
MG2_606	-20.3	10.9

2.1 Sample cleaning

The surface of enamel on each tooth was abraded to a depth of ~100 μm with a tungsten carbide dental burr following the procedure given in Montgomery (2002). The core enamel was removed from the tooth wall with a flexible diamond impregnated cutting disc diagonally from the cusp. The enamel samples were then inspected for any remaining dentine or impurities which, if present, were removed with the burr. Four dentine samples were also taken from the tooth crown beneath the enamel sample. Cleaned samples were sealed in micro-centrifuge tubes and bagged for transfer.

2.2 Sr isotope analysis

Pre-cleaned enamel and dentine samples were prepared and analysed for Sr isotopes at the Arthur Holmes Isotope Geology Laboratory, Department of Earth Sciences, Durham University.

Pre-cleaned enamel chips (6.5 – 18mg) were weighed into clean Teflon beakers and dissolved in 0.5ml ultra-pure Teflon distilled (TD) 3M HNO_3. Once dissolved, Sr was separated from the sample matrix using a 1ml column packed with 60μl of Eichrom Sr Resin. The Sr fraction, eluted from the column in 400μl of ultrapure (MQ) H_2O, was acidified with TD 16M HNO_3 to make a 3% HNO_3 solution ready for isotope analysis by Multi-Collector ICP-MS (MC-ISP-MS) using a ThermoFisher Neptune. Prior to analysis the Sr fraction was tested to determine the Sr concentration by monitoring the ^{86}Sr beam and to ensure the major isotope of Sr (^{88}Sr) did not exceed the maximum voltage (50V) for the detector amplifiers. Where necessary, samples were diluted to yield an ^{88}Sr signal of ~25V.

A Sr isotope measurement comprised a static multi-collection routine, with ^{86}Sr in the axial detector, of 1 block of 50 cycles with an integration time of 4sec per cycle; total analysis time 3.5mins. Instrumental mass bias was corrected for using an ^{88}Sr/^{86}Sr ratio of 8.375209 (the reciprocal of the accepted ^{86}Sr/^{88}Sr ratio of 0.1194) and an exponential law. Corrections were also applied for Kr interferences on ^{84}Sr and ^{86}Sr and the Rb interference on ^{87}Sr by monitoring masses ^{82}Kr, ^{83}Kr and ^{85}Rb. The average ^{83}Kr intensity throughout the analytical session was ~0.1mV, which is insignificant considering the Sr beam size (^{88}Sr between 9 and 25V). The average ^{85}Rb intensity was slightly greater at ~0.3mV (range: 0.1-0.6 mV) but again, given the range in Sr beam size, the Rb correction on the ^{87}Sr/^{86}Sr was very small (<0.00001) and is accurate at that magnitude.

Samples were analysed in three analytical sessions between June 2015 and March 2017. The average ^{87}Sr/^{86}Sr and reproducibility for the international Sr isotope reference material NBS 987 for each session is given in the notes for Table 2. Given the slight variation in average ^{87}Sr/^{86}Sr ratio for NBS 987 between analytical sessions all sample data in Table 2 have been re-normalised to a constant NBS9 987 ^{87}Sr/^{86}Sr ratio of 0.71024. Total procedural Sr blank during chemistry was 28pg, which is insignificant considering that all samples were >0.5μg total Sr in size.

3. Results

Results of ^{87}Sr/^{86}Sr ratio analysis from the non-adult dental enamel, dentine, and animal bone/enamel, including the age at death of each individual and the type of sample used, are given in Table 2.

In all but one child, enamel ratios were between 0.7102 and 0.7134, whereas the range for dentine was smaller and varied between 0.7108 and 0.7119. The lowest of these ratios was observed in individual GC_615, and the highest in MG2_516. Enamel and dentine ratios of individual GC_41 were considerably higher, at 0.7225 and 0.7205, respectively. The enamel ratio exceeded the second highest value observed in this study (MG2_516, 0.7134) by 0.0091, and was clearly an outlier (Figure 4). Enamel $^{87}Sr/^{86}Sr$ ratios had the widest range in children from MG2 (from 0.7107 to 0.7134, range of 0.0027), while ratios in people from the GC and MG1 varied less, when observed without individual GC_41 (ranges of 0.0017 and 0.0018, respectively).

Four individuals analysed for $^{87}Sr/^{86}Sr$ in their dentine and enamel (GC_12, GC_85, MG2_103 and MG2_177) had very similar ratios in both tissue types. In GC_12, GC_85 and MG2_177 the enamel ratio was identical to the dentine, while in MG2_103 the dentine ratio was only by 0.0001 higher than in the enamel, which is not considered a significant difference (Montgomery, 2002: 146). This lack of difference suggests that no diagenetic shift in $^{87}Sr/^{86}Sr$ had occurred, as explained in Section 1,1 above. In GC_41, however, the enamel Sr isotope ratio was 0.002 higher than the dentine, which is significant, compared to the other four individuals.

Table 2. Results of $^{87}Sr/^{86}Sr$ ratio analysis from the dental enamel, dentine and animal bone.

Individual	**Age at death**	**Element**	**Tissue**	**$^{87}Sr/^{86}Sr$ norm**	**2SE**
General cemetery					
[1]GC_12	13-14	C'	Enamel	0.71191	0.000010
[1]GC_12 dent			Dentine	0.71194	0.000015
[1]GC_41	14-15	C,	Enamel	0.72247	0.000010
[3]GC_41 dent			Dentine	0.72045	0.000010
[1]GC_63	7-8	I1,	Enamel	0.71094	0.000010
[1]GC_85	12-13	PM2,	Enamel	0.71176	0.000009
[1]GC_85 dent			Dentine	0.71167	0.000010
[1]GC_134	13-14	C'	Enamel	0.71181	0.000007
[1]GC_283	8-9	C,	Enamel	0.71162	0.000013
[1]GC_615	10-11	C,	Enamel	0.71019	0.000009
[1]GC_615 rep				0.71016	0.000012
Mass grave 1					
[1]MG1_83	10-11	C'	Enamel	0.71180	0.000011
[1]MG1_127	11-13	C'	Enamel	0.71102	0.000010
[1]MG1_156	9-11	C'	Enamel	0.71252	0.000009
[1]MG1_497	13-14	C'	Enamel	0.71074	0.000013
[1]MG1_627	10-11	C,	Enamel	0.71120	0.000012
[1]MG1_630	11-12	C,	Enamel	0.71189	0.000010
Mass grave 2					
[1]MG2_103	10-11	C'	Enamel	0.71089	0.000010
[1]MG2_103 dent			Dentine	0.71102	0.000012
[1]MG2_177	10-11	C'	Enamel	0.71070	0.000012
[1]MG2_177 dent			Dentine	0.71067	0.000015
[1]MG2_432	10-11	C'	Enamel	0.71091	0.000009
[1]MG2_508	8-9	C,	Enamel	0.71073	0.000008
[1]MG2_516	10-11	C,	Enamel	0.71342	0.000011
[1]MG2_606	10-11	C,	Enamel	0.71262	0.000009
Animal bone					
Site	**Species**				
[2]Cesis	Sheep/goat	Molar'	Enamel	0.71310	0.000008
[3]Limbazi	Cattle	Metacarpal	Bone	0.71373	0.000009
[3]Mazstraupe	Pig	Mandible	Bone	0.71490	0.000009
[2]RigaStPeter1	Cattle	Vertebra	Bone	0.71248	0.000008
[2]RigaStPeter2	Pig	Humerus	Bone	0.71206	0.000008
[2]RigaDome	Pig	Radius	Bone	0.71200	0.000010
[3]Old Riga site	Cattle	Mandible	Bone	0.71203	0.000009

Notes: Superscripts in column 1 refer to analytical sessions

[1]: Session 1 23-06-15: NBS 987 = 0.710280±20 (2SD, n=10)

[2]: Session 2 04-05-16: NBS 987 = 0.710255±11 (2SD, n=6)

[3]: Session 3 08-03-17: NBS 987 = 0.710261±16(2SD, n=8)

dent-dentine; rep-repeat; C-canine; I1-first incisor; PM2-second premolar; ‘-upper; ,-lower; RigaStPeter – St Peter’s Church cemetery in Riga; RigaDome – Riga Dome Church cemetery.

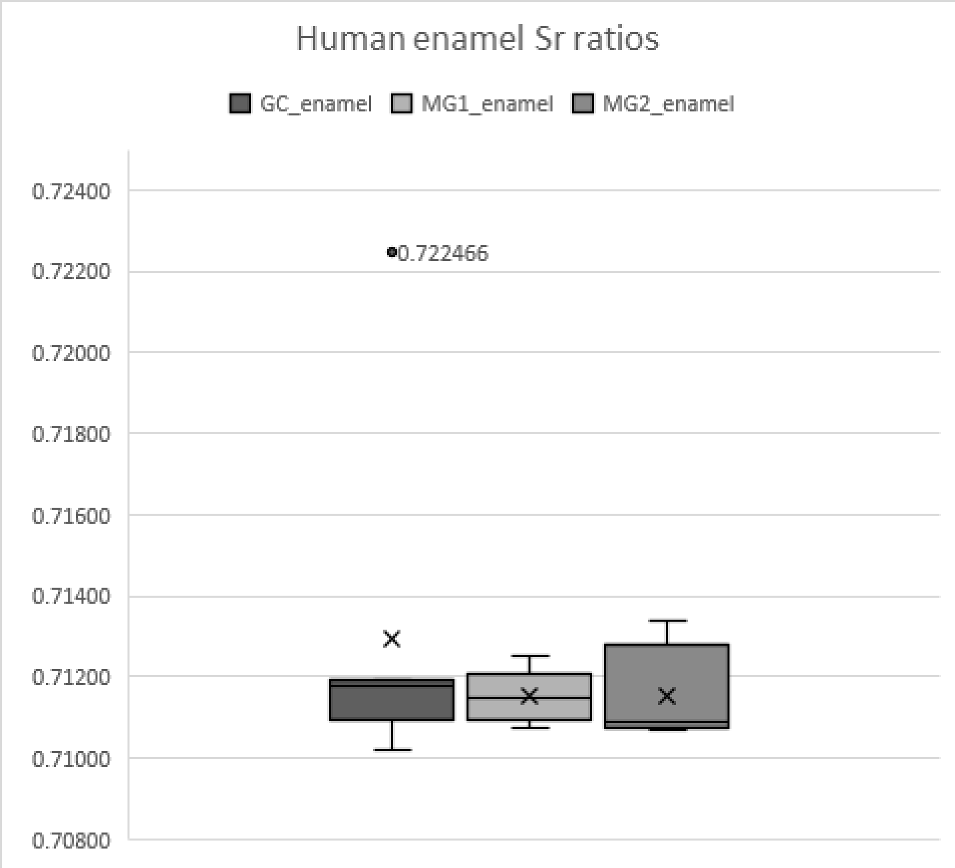

Figure 4. Human enamel $^{87}Sr/^{86}Sr$ ratios, including individual GC_41 (shown as an outlier); boxes are formed by the first and the third quartiles; the dividing line shows the median ratio; the whiskers on each box show minimum and maximum ratios; x-mean ratio; N(GC)=7, N(MG1)=6, N(MG2)=6.

Faunal samples from Vidzeme ranged from 0.71310 to 0.71490, while those from Riga were between 0.71200 and 0.71248. Although the medians of the two groups (0.71373 and 0.71204, respectively) differed by 0.0017, due to the small sample size, the differences could not be compared with a statistical significance test.

There were no significant differences in median human enamel Sr isotope ratios between the three contexts (Kruskal-Wallis test, n=18, H=0.42, df=2, p=0.811). The human enamel samples were significantly different in median to the faunal samples from Vidzeme (Mann-Whitney non-directional test, n=21, U=1, Critical Value=7), although the ratio of one child (MG2_516) overlapped with the faunal samples from Vidzeme (Figure 5). While enamel ratios from children buried in MG1 and MG2 were not significantly different in median to faunal samples from Riga (n=16, U=12, Critical Value=7), the opposite was true for children buried in the GC (n=10, U=0, Critical Value=2), and all the dentine ratios (n=8, U=0, Critical

Value=0). There were no significant differences between the human enamel and dentine samples (n=22, U=33.5, Critical Value=12).

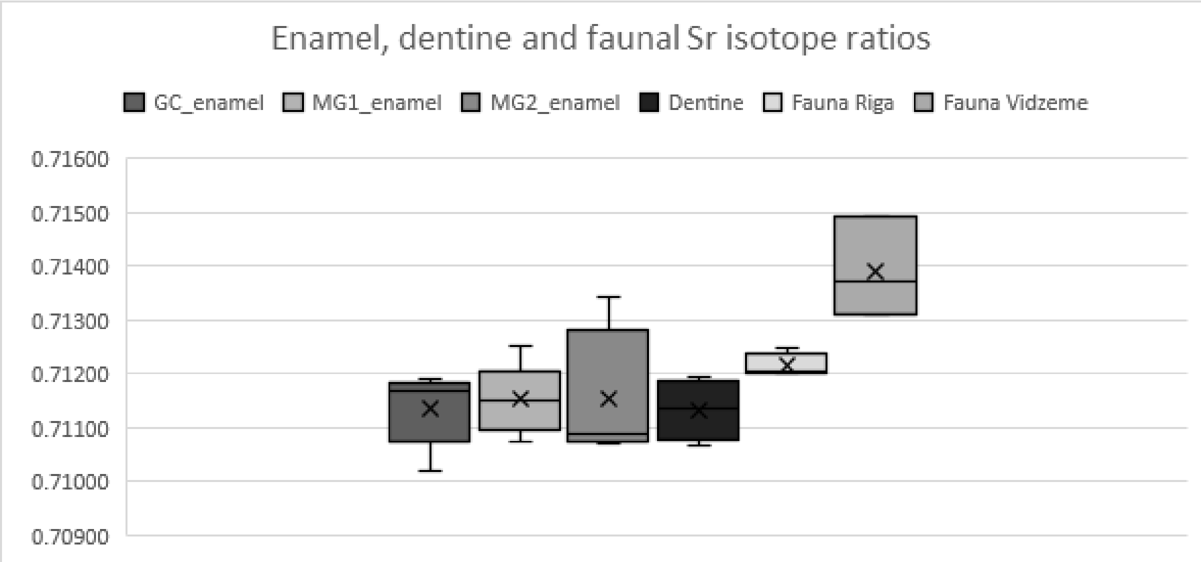

Figure 5. Enamel, dentine and faunal $^{87}Sr/^{86}Sr$ isotope ratios, plotted without individual GC_41; boxes are formed by the first and the third quartiles; the dividing line shows the median ratio; the whiskers on each box show minimum and maximum ratios; x-mean ratio; N(GC)=6, N(MG1)=6, N(MG2)=6; N(dentine)=5; N(Fauna Riga)=5; N(Fauna Vidzeme)=3.

4. Discussion

The ratios observed in most children, except GC_41, are consistent with the expected ratios in soil dominated by Devonian deposits, as discussed in Section 1.1 above. Moreover, as enamel and dentine ratios in people from all three contexts differ significantly from faunal samples from Vidzeme, this supports the possibility that there are noticeable differences between regions of Latvia, despite largely homogenous underlying geology. The overlapping of Sr isotope ratio in individual MG2_516 with faunal samples from Vidzeme suggests that this individual may have derived from that area. In contrast, the lack of variation in all human enamel and dentine samples makes it plausible that most other children originated from a similar location, most probably Riga and its vicinity, thus rejecting hypothesis 1 of this study. Caution is necessary, however, before the differences in local soil biosphere ranges between Riga and rural Vidzeme, and thus the “local” or “non-local” origins of the sampled individuals, can be confirmed. This is because the difference in ratios between the faunal sample from Cesis, and individuals MG1_156 and MG2_606, as well as one faunal sample from St Peter’s church in Riga, were only 0.0006, or less.

The observed significant differences between enamel ratios in children from the GC, and all human dentine ratios, against faunal samples from Old Riga are intriguing, considering that the distance between the cemetery and the city is approximately 1km. This might be explained by the small faunal sample size. As discussed in Section 1.1 above, $^{87}Sr/^{86}Sr$ ratio in archaeological bone, like in dentine, is prone to a diagenetic shift towards that of the burial soil (Hoppe et al., 2003, Lee–Thorp, 2002, Nelson et al., 1986). All four faunal samples in the current study came from different sites within the old city of Riga, but three yielded insignificant differences, with $^{87}Sr/^{86}Sr$ ratios almost overlapping (one sample from St Peter's Church cemetery, as well as samples from Riga Dome Church cemetery, and another archaeological site in the old city). Consequently, significantly different dentine ratios of children from all three contexts suggest a noticeable difference in soil composition between the two locations, and more research is therefore necessary to clearly define the local soil biosphere range of inner Riga, as already mentioned above.

The almost identical enamel and dentine ratios of the analysed children, however, are suggestive of a lack of a diagenetic change in these samples. This is difficult to explain, considering that all individuals had been buried in soil, and that most studies have reported a diagenetic shift in similar conditions (Budd et al., 2000). The only individual where a noticeable diagenetic shift had occurred was GC_41. According to the study of Budd et al. (ibid.), the observed shift is still smaller than is expected in normal burial conditions, whereby diagenetic Sr in dentine would be closer to the value of the soil in most individuals, rather than their biogenic Sr. To explore the observed similarities and differences further, more analysis of further dentine, and faunal samples from both St Gertrude's cemetery and old Riga would be necessary.

The very radiogenic $^{87}Sr/^{86}Sr$ composition of enamel for GC_41 suggests this individual most likely derived from an area with an underlying geology different to that of Vidzeme or Riga and its surroundings. The closest comparable populations are from Estonian prehistoric coastal sites, where human $^{87}Sr/^{86}Sr$ ratios ranged from 0.7106 to 0.7137, which is similar to children from St Gertrude's cemetery, while two individuals from the site of Kunda had considerably higher values than the rest of the population, exceeding 0.7188 (Oras et al., 2016). This enabled the authors of the study to suggest that these people were non-local not only for the observed sites, but possibly for the territory of Estonia. The value of GC_41 was even higher than that for the two immigrants in Kunda. The closest comparable Sr isotope compositions from the wider region come from northern and central Sweden, with an average range of 0.720-0.726 (Price et al., 2012), while ratios from the islands in the Baltic sea and from Poland were lower (Gregoricka et al., 2014, Price et al., 2012), and those from Finland were higher (Bläuer et al., 2013).

The second hypothesis of this study addressed the identification of children from mass graves, who had possibly derived from the same communities, based on similar incremental dentine $\delta^{13}C$ profiles. To test the second hypothesis, Sr values were plotted against mean $\delta^{13}C$ values (Figure 6). In order to also explore correlations between $\delta^{13}C$ values and $^{87}Sr/^{86}Sr$ ratios and therefore to identify possible immigrants from coastal areas, this analysis included all human enamel samples. The lower $^{87}Sr/^{86}Sr$ ratios (median 0.7108) of individuals MG1_127, MG2_177, MG2_432 and MG2_508 (Figure 3) were consistent with the highest $\delta^{13}C$ incremental dentine profiles observed in the population (Petersone-Gordina et al., forthcoming (a)).

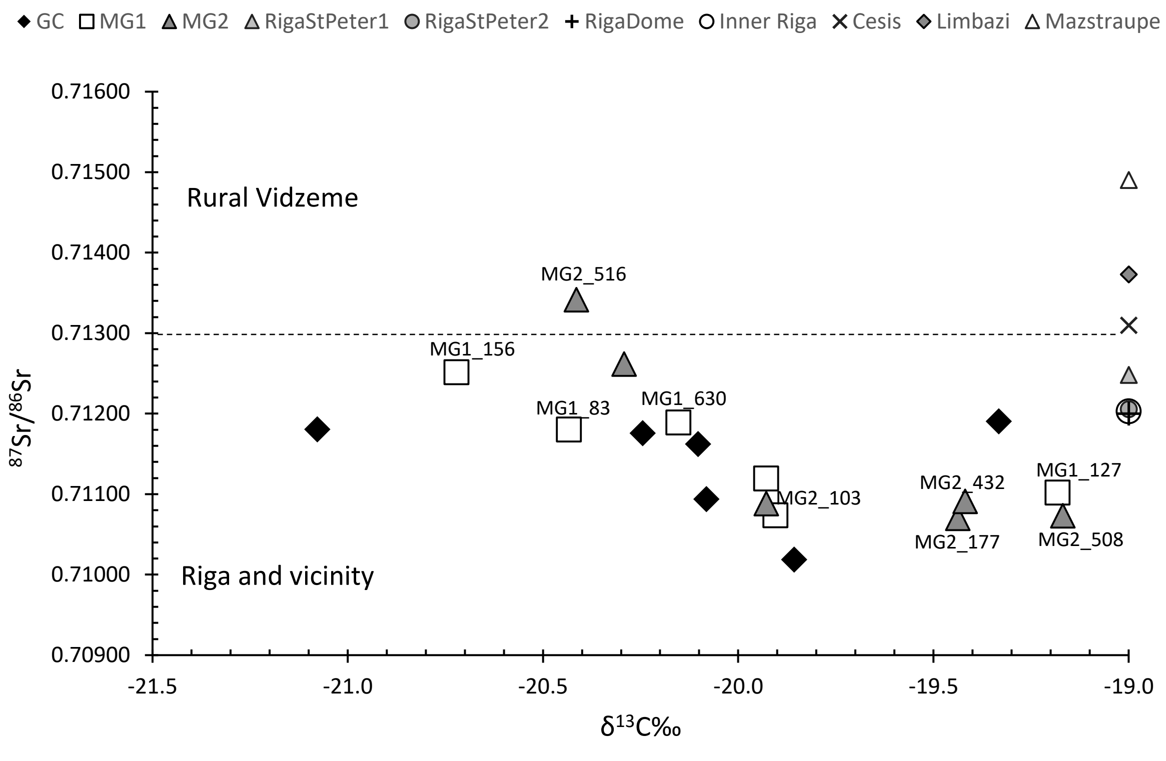

Figure 6. $^{87}Sr/^{86}Sr$ ratios of 18 children and seven animals against mean $\delta^{13}C$ values. Animal values are on the right axis; their $\delta^{13}C$ values are unknown. Individual GC_41 is not included in this figure. Children who are discussed with regard to their mean $\delta^{13}C$ values/incremental dentine profiles are shown in this graph with their burial numbers. The line separates approximate bioavailable $^{87}Sr/^{86}Sr$ ranges for Riga and rural Vidzeme, based on enamel, dentine, and faunal samples.

It also emerged that there was a significant negative correlation between mean dentine $\delta^{13}C$ values and enamel $^{87}Sr/^{86}Sr$ ratios in all children from MG1 and MG2 (r= -0.8; r^2=0.7; p=0.047; df=4; t=-2.84 and r=-0.9; r^2=0.8; p=0.015; df=4; t=-4.07, respectively), whereby those individuals with higher $\delta^{13}C$ values, which indicates a higher proportion of marine protein in their diet, had Sr isotope compositions that were lower, and closer to marine values. Conversely, the correlation between $^{87}Sr/^{86}Sr$ ratios and $\delta^{13}C$ values was weak (r=-0.2; r^2=0.02; p=0.786; df=4; t=-0.29) in children from the GC. It is therefore possible that most individuals from the mass graves came from coastal regions, albeit from an area geologically indistinguishable from Riga. It is also possible that a higher proportion of marine foods was included in the diet of these children, which brought their $^{87}Sr/^{86}Sr$ ratios closer to the current seawater ratio of 0.7092 (Bentley, 2006). However, a recent study on pigs comparing $^{87}Sr/^{86}Sr$ ratios in groups with and without marine protein in the form of fishmeal in diet was inconclusive with regard to dietary influence (Lewis et al. 2017).

The similar $\delta^{13}C$ profiles and mean $\delta^{13}C$ values of individuals MG1_83 and MG2_516 were not supported by similar $^{87}Sr/^{86}Sr$ ratios, as these differed by 0.0016 (Figure 3). While this is not a considerable difference, the ratio of MG2_516 overlapped with those of faunal samples from rural Vidzeme, as discussed above, and it is possible that this individual was an immigrant from that area; MG1_83, however, fell within the "local" range. As already noted above, however, the difference between two "local" human and one faunal Vidzeme ratio was less than 0.0006, and there remains a possibility that all sampled individuals were local or derived from geologically similar areas. Without evidence of $\delta^{13}C$ values and $^{87}Sr/^{86}Sr$ ratios from other contemporary populations in rural Vidzeme and other regions of Latvia, the observed similarities between these two individuals are difficult to interpret.

On the other hand, the similarities in the $\delta^{13}C$ profiles of MG1_630 and MG2_103 might be consistent with growing up in the same community, since the $^{87}Sr/^{86}Sr$ ratios of both children were within the "local" range and differed by 0.0010 (Figure 3). Likewise, the $^{87}Sr/^{86}Sr$ ratios of the third group of children with similar $\delta^{13}C$ profiles also fell within the "local" range, and thus could be linked to similar food strategies within the same community, especially with regards to marine protein, as discussed above. Notably, the ratios of MG2_177 and MG2_432 only differed by 0.0002, which has previously been observed in modern siblings (Montgomery 2002: 146). The almost identical $\delta^{13}C$ profiles of the two children, combined with an insignificant difference between their $^{87}Sr/^{86}Sr$ ratios, might suggest that these children were related, although this can only be confirmed by ancient DNA analysis.

The child with the lowest $\delta^{13}C$ and $\delta^{15}N$ values (MG1_156), also had the second highest $^{87}Sr/^{86}Sr$ ratio for MG samples, second only to MG2_516. Unlike individual MG2_516, who may have originated from the Vidzeme area, MG1_156 had a Sr isotope composition only 0.00003 lower than the highest value defined by the local Riga faunal samples (Figure 3), which suggests that this individual was perhaps from Riga. The observed differences in dietary isotope profiles thus point to different individual dietary practices, especially with regard to marine and terrestrial foods, rather than a different origin for this child.

5. Conclusions

The first hypothesis, that most individuals from the GC derived from the local community while people in mass graves were immigrants was rejected, based on the lack of statistical differences in $^{87}Sr/^{86}Sr$ enamel ratios between the groups. More research, however, is necessary to clearly define the local soil biosphere ranges for parts of Vidzeme and inner Riga, before “local” or “non-local” origins for people buried in the cemetery can be confirmed.

The second hypothesis, that children with similar incremental dentine $\delta^{13}C$ profiles would have derived from the same community was partly supported. One pair of individuals comprised a child who might have derived from rural Vidzeme, and a local individual. The other two groups of individuals with similar $\delta^{13}C$ profiles, however, did probably come from the same community.

This study has met its main aim and helped to shed light on the origin of people buried in St Gertrude’s cemetery, suggesting that most people originated in Riga and its vicinity. More importantly, this research has generated the first archaeological $^{86}Sr/^{87}Sr$ ratios from Latvia, not only indicating the future potential for local migration studies, but also producing valuable comparative data to aid future research related to past migration in Europe. To explore the findings of this study further, it will be necessary to obtain more $^{86}Sr/^{87}Sr$ data from different regions of Latvia, with the aim of eventually creating a regional $^{86}Sr/^{87}Sr$ map.

Acknowledgements

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Chapter 7. Manuscript 4

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Exploring differences in physical health and living conditions between populations buried in the 15th – 17th century St Gertrude Church cemetery in Riga, Latvia

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Key words: Scurvy, rickets, compromised childhood health, maxillary sinusitis, non-specific periosteal lesions, heterogeneous frailty, post-medieval, Baltic region

Abstract

The aims of this study were, through observing the presence/absence of indicators of stress, 1) to compare particular aspects of physical health of people buried in the general cemetery and two mass graves of the St Gertrude Church cemetery, Latvia, Riga, and 2) to test if the prevalence rates of any pathological lesions could indicate higher frailty for people in the mass graves. The skeletons of 703 men, women and children were observed for the presence of cribra orbitalia, linear enamel hypoplasia, bone changes representing respiratory disease (maxillary sinusitis and rib lesions), vitamin C and D deficiencies, and non-specific periosteal reaction on long bones. Children in the mass graves had significantly more hypoplastic lesions than children in the general cemetery ($p<0.001$). The co-occurrence of enamel hypoplasia and cribra orbitalia was also significantly more prevalent in children from the mass graves ($p=0.003$). Vitamin deficiencies were observed almost exclusively in children from the general cemetery, while residual rickets proved to affect a similar number of adults from both contexts. Periosteal lesions affected femora in significantly more older men from the mass graves than the general cemetery ($p=0.041$), but the prevalence of woven bone was higher in males from the general cemetery. Overall, the data suggest that compromised health in childhood and ongoing conditions may have predisposed people in mass graves to higher frailty, and that risk factors inherent in the working and/or living conditions of people were considerably different for children, men and women from the two population groups.

1. Introduction

This paper is the final in a series of four defined studies based on the population buried in the St Gertrude Church Cemetery in Riga, Latvia, dating from the late 15th – late 17th centuries AD (Actiņš et al., 2009) (Figure 1). The site was excavated in 2006 and is remarkable compared to most other post-medieval cemeteries in Riga and in wider Europe because of the presence of two 17th century mass graves, which were identified among the single discrete burials in the general cemetery. Historical evidence suggests that several events in the 17th century caused catastrophic mortality in Riga and the whole Vidzeme region, and particularly a severe famine and two plague epidemics in the early 1600s (Dunsdorfs, 1962, Napiersky, 1890). This resulted in migration of people from rural areas to Riga with the aim of accessing help for their very survival. The possible presence of rural immigrants in the cemetery was the reason why the three previous studies addressed the identification of different population groups within it using stable isotope and dental disease analyses (Petersone-Gordina et al., Forthcoming (b), Petersone-Gordina et al., Forthcoming (a), Petersone-Gordina et al., 2018).

Figure 1. Map of Latvia showing the location of Riga and the city of Jelgava (discussed in Section 4.3), and a small map of Europe showing the location of Latvia (right upper corner).

Firstly, the prevalence of dental disease in the whole cemetery population, along with carbon and nitrogen isotope values determined from adult bone samples, were assessed and compared in all three contexts (the general cemetery and each mass grave). Several significant differences in dental attrition rates, as well as calculus deposits, suggested that the characteristics of the population groups in each context were different, but that there were more differences between people buried in the two mass graves and the general cemetery, than between the mass graves themselves. Carbon and nitrogen isotope values, however, were similar between men and women from different contexts. Secondly, carbon and nitrogen profiles of incremental dentine samples from 19 children revealed evidence for nutritional stress in children from one of the mass graves towards the end of their lives, suggesting that they were the victims of a famine; likewise, the dietary profiles of several children from both mass graves were similar, suggesting the presence of people from the same population groups in both, but not the general cemetery. Finally, strontium analysis using enamel and dentine samples from the same 19 children, revealed only subtle differences between children in the general cemetery and the mass graves, while contrasting ratios of faunal samples from rural Vidzeme yielded significant differences in all three contexts. Despite the small sample size, this was taken as evidence that most people buried in the cemetery originated from near Riga, and probably from Gertrude village. The overlapping values of one child from the mass graves, with faunal samples from Vidzeme, however suggested that some rural immigrants might have been buried amid the local population in mass graves.

Based on previous evidence, this study assumes that most of the people buried in the general cemetery and mass graves were local (from Gertrude village), keeping in mind that people from other communities, including rural Vidzeme, as well as the city of Riga, might also have been buried in the mass graves. Because the people in the mass graves are not believed to represent two distinctive population groups, they are studied together as one “population”.

The population groups from the general cemetery and the mass graves are compared with regard to the presence of pathological lesions which could be associated with particular physical health problems. These included evidence for previous episodes of compromised childhood health, as expressed in cribra orbitalia, linear enamel hypoplasia, and residual rickets, as well as ongoing health problems, such as respiratory infections, evidence for active vitamin C and D deficiencies, and non-specific periosteal reactions on long bones (for inclusion criteria of these pathological conditions, see Section 1.2 below). It was considered that these pathologically induced conditions would best highlight differences in living conditions, and certain aspects of physical health between the population groups, and would encompass both episodes of arrested growth in early childhood and indicators of poor physical health in later life. Moreover, different prevalence rates in pathological lesions might also point to increased frailty in people buried in the mass graves.

The aim of this study was to compare the physical health status of the locally derived population from Gertrude village, buried in the general cemetery (GC), and the population group, probably including putative immigrants, buried in the mass graves (MGs). The hypotheses proposed were as follows:

1) Prevalence rates for pathological lesions will be significantly different between the people buried in the general cemetery and the mass graves, based on the assumption that they represent population groups from different centuries, and one or two generations who died as a result of a catastrophic mortality event, respectively;

2) Prevalence rates for pathological lesions which could have resulted from physiological and/or nutritional stress in childhood (cribra orbitalia, linear hypoplasia, scurvy) as well as evidence for poor physical health in adults (periosteal reactions) will be lower in the general cemetery, because previous or ongoing physiological stress episodes might have predisposed people buried in the mass graves to increased frailty during events causing catastrophic mortality.

To place St Gertrude's cemetery population in context, a brief historical background is given in the following section.

1.1 Historical background

St Gertrude Church was built around 1413 outside the old centre of Riga, and next to the main road leading to/from the rural Vidzeme region, of which Riga is the capital, and beyond to Estonia and Russia (Pīrangs, 1932). The church and the cemetery around it were both used by people from the nearby Gertrude village, whose population was mostly comprised of small-scale farmers. The site was also linked with a road to the nearby St George's hospital, and likely used as the hospital's church and cemetery (Šterns, 1998) (Figure 2). Riga's status as a key trading centre provided the Gertrude population with direct access to resources available in the city, as well as to its markets where local people could trade their own produce (Dunsdorfs, 1962). The area around Gertrude village was mainly reserved for the allotment gardens that belonged to the citizens living in the inner city; this allowed the suburban population to benefit from less crowded living conditions (Šterns, 1998). However, living outside the city walls, this suburban population was much less protected than the city population and, during warfare, most buildings were destroyed ahead of sieges to deprive the invading army of potential shelter and resources. The suburbs of Riga were thus destroyed in 1559, 1605 and 1710 (Dunsdorfs, 1962).

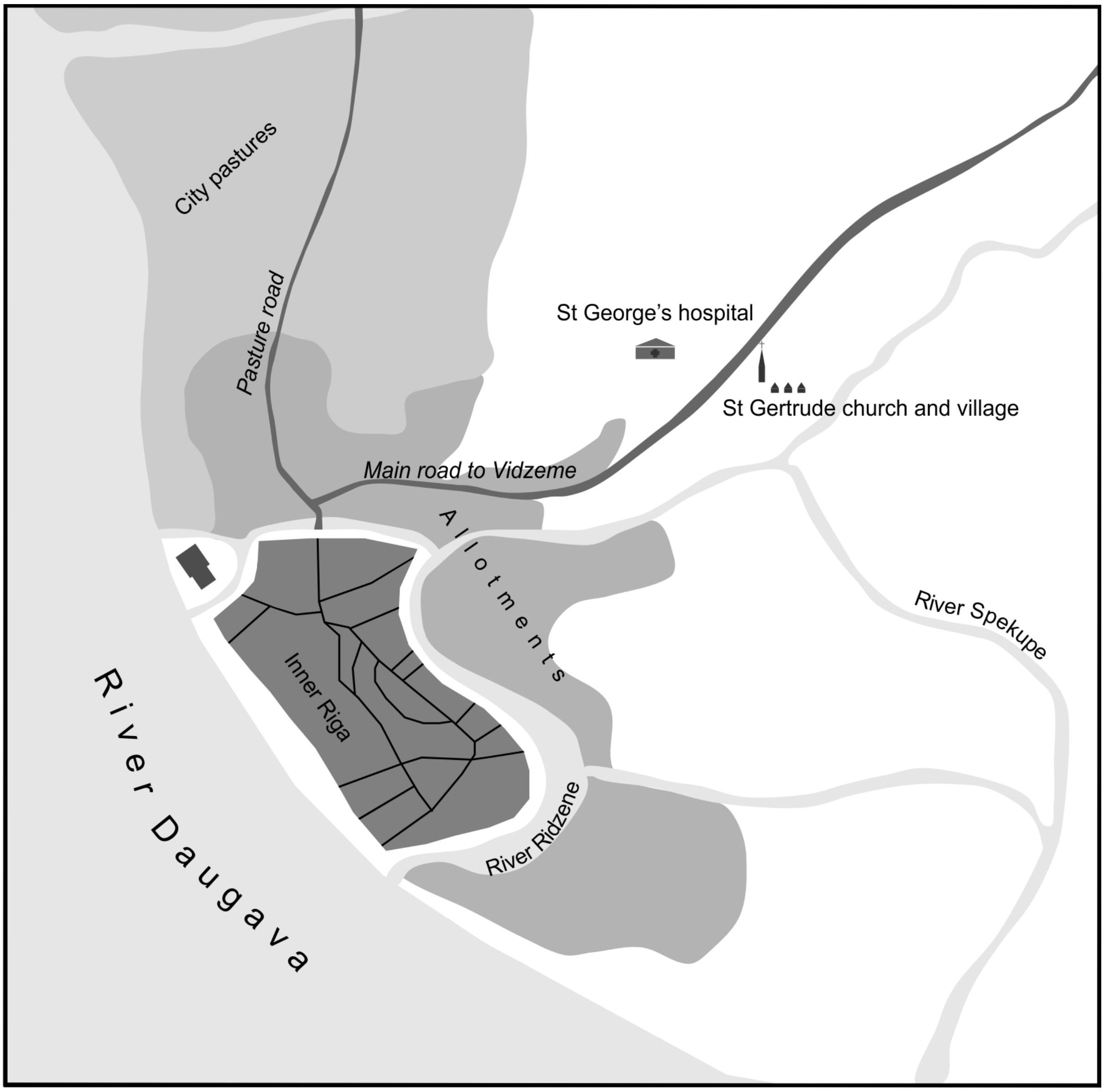

Figure 2. Map of medieval Riga and its suburbs, showing St Gertrude's cemetery and St George's hospital (adapted from Šterns, 1998: 350).

The 17th century was a particularly turbulent time for Riga and the whole region of Vidzeme, with the Polish-Swedish war (1600-29) and two plague epidemics (1602 and 1623) affecting the region within a relatively short period (Napiersky, 1890). The start of the war was particularly significant because the army raided the livelihoods of the Vidzeme farmers in 1600, a year of a notably poor harvest, thus leaving many with no food supplies. This caused large-scale migration of poor farmers to Riga in the winter of 1601-2 and, although some food was provided by the city, mortality was very high due to cold and exhaustion (Napiersky, 1890). A large proportion of the migrants are believed to have been buried in St Gertrude's cemetery (Actiņš et al., 2009, Pīrangs, 1932, Rusovs, 1926). The presence of 17th century mass graves in the cemetery supports the alleged episodes of mass mortality during this period. While the cemetery was likely used as the final resting place for rural immigrants from Vidzeme, it also might have accommodated plague victims in Riga, who could not be buried inside the city due to lack of space (Pīrangs, 1932).

1.2 Analysis of morbidity

All pathological lesions considered in this study were included according to their potential for revealing different aspects of physical health in a past population. Each of them will be briefly described below, to explain how their prevalence rates might be interpreted.

Cribra orbitalia, or abnormal porosity of the orbital roof where the pores penetrate the lamellar bone surface, was primarily included in this study because of its potential to reveal compromised childhood health (Larsen, 2015: 30-41, Roberts and Manchester, 2010: 222-3, Walker et al., 2009). Cribra orbitalia has been proven to be a condition that develops in childhood, due to the age-related characteristics of the periosteum (Allen et al., 2004, Halvorsen and Bechensteen, 2002, Kent, 1986, Ma'luf et al., 2002, Stuart-Macadam, 1985, 1992, Tonna, 1974). Possible aetiologies include acquired or genetic anaemia, especially when co-occurring with similar, porous lesions on the skull vault, porotic hyperostosis (Holland and O'Brien, 1997, Lanzkowsky, 1968, Mittler and van Gerven, 1994, Ortner, 2003: 363-4, Oxenham and Cavill, 2010, Ross and Logan, 1969, Stevens et al., 2013, Stuart-Macadam, 1987a, 1987b, 1992), subperiosteal inflammation caused by vitamin C and D deficiencies, as well as conditions causing subperiosteal haematomas (Ma'luf et al., 2002, Sabet et al., 2001, Saint-Martin et al., 2015, Wapler et al., 2004, Woo and Kim, 1997).

Enamel hypoplasia is representative of disrupted enamel formation on the tooth crown in childhood, and such defects can be either hereditary (Witkop, 1988), or environmental (traumatic, or caused by systemic metabolic stress, such as nutritional deficiencies and/or certain diseases - Fiumara and Lessell, 1970, Goodman and Rose, 1991, Hillson, 1996: 165-6, Larsen, 2015: 44-7, Rajendran, 2009, Seow and Perham, 1989). In most archaeological populations, linear enamel hypoplasia (LEH), or enamel defects that affect numerous teeth in the same individual, are believed to have resulted from episodes of arrested growth in childhood, during the formation of the tooth (Dobney and Goodman, 1991, Goodman and Rose, 1991, King et al., 2005).

Sinusitis (inflammation of the paranasal sinuses) is a common condition today, with the acute form affecting around 15% of the living population in western countries (Eloy et al., 2011). The condition is most commonly the result either of a viral infection, rhinitis (inflammation of the inside of the nose), or dental infection (Ah-See and Evans, 2007, Chapnik and Bach, 1976). A high prevalence of sinusitis in an archaeological population might point to crowded living conditions, whereby viral or bacterial infections causing sinusitis could spread easily by means of droplets containing the virus or bacteria expelled during coughing and sneezing (Boocock et al., 1995), and/or indoor/outdoor air pollution (see discussion).

Rib lesions, if present on the visceral aspect of ribs in skeletal remains, can be interpreted as evidence for lower pulmonary infections, including pneumonia, and Tuberculosis (TB). Ribs can become involved if a chronic infection from the lungs spreads via the pleura (Eyler et al., 1996), and the lesions have been reported in archaeological and historical populations known to have died from TB, and/or pneumonia (Roberts et al., 1994, Santos and Roberts, 2001).

The presence of vitamin C and D deficiencies was considered in this study for their potential to reveal possible evidence for an inadequate diet and compromised living conditions, particularly exposure to ultraviolet light; consequently, differences were explored in relation to living conditions in terms of access to a well-balanced diet and a good quality living environment, for the population.

Vitamin C deficiency (scurvy) causes weakness of blood vessels, which initially results in bleeding and haemorrhagic skin lesions, and progressively, affects larger blood vessels, and subsequent bleeding at various sites inside the body, particularly joints and lower extremities, and the gingiva (Hirschmann and Raugi, 1999, Olmedo et al., 2006, Shah and Sachdev, 2012, Touyz, 1997). If left untreated, it can eventually result in weakening and fragility of bones, and cause fractures (Golriz et al., 2017, Gupta et al., 1989, Shah and Sachdev,

2012). Because of inherent rapid growth and bone formation, bone involvement is more severely manifested in children (Agarwal et al., 2015, Ortner, 2003: 384-6).
Vitamin D deficiency (rickets in children, osteomalacia in adults) is a systemic disease which mostly results from inadequate exposure to sunlight, especially in infants and children (Holick, 2006). On the other hand, some foods are high in vitamin D, such as oily fish and milk and, if used in sufficient amounts, can help prevent deficiency (Holick, 2006). One of the consequences of vitamin D deficiency is poor bone mineralisation, which can result in weight-bearing bone deformities. These are much more common in children, as bones grow and remodel rapidly in this cohort (Huldschinsky, 1928, Pettifor, 2005). Most commonly, rickets occurs in children between the ages of three and 18 months, before they can freely walk outdoors, and if the sources of dietary vitamin D are inadequate, especially with regards to breastmilk (Hollis and Wagner, 2004, Merewood et al., 2010, Pettifor, 2003: 544). In adults, pregnant or lactating females have been proven to be most at risk, because of increased demands for calcium accumulation in the body (Prentice, 2003: 249). Likewise, elderly people are at greater risk of becoming vitamin D deficient when frailty prevents venturing outdoors, or due to extensive clothing (Halloran and Portale, 1997, Wyskida et al., 2017).

Finally, periosteal reaction on the long bones of the arms and legs was recorded in this study because it can aid in a diagnosis of vitamin C deficiency in skeletal remains, but also indicate another recent or ongoing pathological condition. The lesions are thought to be the result of periosteal inflammation with a subsequent underlying bone reaction. It seems to occur in a variety of specific conditions, including scurvy, leprosy, TB and treponemal disease, as well as trauma (Resnick and Niwayama, 1995: 4435, Roberts and Manchester, 2010: 172, Weston, 2008). Where periosteal reactions on long bones occur without any evidence for other changes in the skeleton which could be linked to a specific condition, they can be classed as non-specific, although care must be taken when recording incomplete skeletons (Klaus, 2014, Weston, 2008). Recent research has suggested a link between active periosteal lesions (as expressed by the presence of woven bone) and a higher risk of mortality (DeWitte and Stojanowski, 2015, DeWitte and Wood, 2008). In this study, skeletal analysis was limited to certain skeletal elements, and therefore several specific infections, including TB and venereal syphilis, might have been missed. As suggested by Yaussy et al. (2016), however, these conditions would still be representative of compromised physical health and thus, an indicator of the living conditions in the population.

2. Materials and methods

All 721 individuals excavated from the St Gertrude Church Cemetery were used in this study. In total, there were 420 people in the general cemetery (GC) and 301 in the mass graves (MGs). Some aspects of the reconstructed demographic profile (Gerhards, 2009a, Petersone-Gordina et al., 2018) were characteristic of a catastrophic mortality for those buried in both mass graves, whereby most age groups are equally represented (Keckler, 1997). This was particularly true for the children. The results of previous studies on the prevalence of dental disease and dietary stable isotope analysis, as well as incremental dentine analysis, were used to support the Discussion.

A summary of methods used for age at death and sex estimation is given in Table 1 (from Petersone-Gordina et al., 2018).

Table 1. Methods used for sex and age at death estimation.

Method	Reference
SEX ESTIMATION	
Morphological traits of the pelvis and skull	Buikstra and Ubelaker, 1994: 16-20, Milner, 1992, Phenice, 1969
AGE ESTIMATION	
NON-ADULT	
Tooth formation and eruption	AlQahtani et al., 2010
Epiphyseal fusion of the long bones	Ogden et al., 1978, Schaefer, 2008
Long bone length	Fazekas and Kósa, 1978, Maresh, 1970
ADULT	
Degeneration of the pubic symphysis	Brooks and Suchey, 1990
Degeneration of auricular surface	Buckberry and Chamberlain, 2002, Lovejoy et al., 1985, Meindl et al., 1985
Degeneration of sternal rib ends	Işcan et al., 1984, 1985, Loth and Iscan, 1989
Cranial suture closure	Meindl and Lovejoy, 1985

All individuals were assessed for the presence of cribra orbitalia and porotic hypeorostosis, linear enamel hypoplasia, vitamin C and D deficiencies, periosteal reactions on long bones, and respiratory infections, as expressed in sinusitis and rib new bone formation. All individuals with at least one of the selected skeletal elements observable, were included in the study (Table 2).

Cribra orbitalia was recorded as present or absent in every adult and non-adult individual with at least one observable orbit preserved for observation, as defined by Stuart-Macadam, (1991). The state of healing of the lesion, however, was considered, and recorded as healed, whereby only porous lesions were present, or active, with trabecular outgrowth clearly visible on the surface of the bone (Mensforth et al., 1978, Walker et al., 2009).

Enamel hypoplasia was recorded as present only if the hypoplastic defects were visible without magnification. The tooth was recorded as not observable if considerable calculus deposits were present on the crown, or if most of the crown was missing due to extensive caries, wear or post-mortem damage. For each observable affected tooth, the defects were scored as slight (one defect per tooth) or medium to severe (two or more defects per tooth) (Buikstra and Ubelaker, 1994: 56-7, Ogden, 2008, Roberts and Connell, 2004). No attempt was made to calculate the age of formation of the defect as this was outside the scope of this research.

To compare evidence for single and multiple episodes of compromised childhood health in people buried in the mass graves and the general cemetery in order to explore whether there was a higher risk of mortality during famines and/or epidemics, individuals with either cribra orbitalia, or LEH were compared to people with both pathological lesions present.

To observe possible evidence for scurvy, different skeletal elements were examined in adult and non-adult individuals for a variety of pathological lesions (Table 2). Porosity on the bones was treated as abnormal if dense, small (less than 1mm in diameter) holes were seen to be penetrating the lamellar bone surface (Ortner and Ericksen, 1997). A hand lens (x 12 magnification) was used to aid the analysis. The pathological lesions were recorded as present or absent in all adult and non-adult individuals. In adults, previously acquired data on periodontal disease (Petersone-Gordina et al., 2018) was used in combination with the prevalence of bilateral lesions on the long bones of the legs, since both are known to co-occur in archaeological populations known to have experienced scurvy (Ortner, 2003: 387, van der Merwe et al., 2010). The presence of bilateral new bone formation in the orbits, and on the long bones of the legs was recorded for all individuals where these bone elements were present. In non-adults, a diagnosis of possible scurvy was made if at least two relevant skeletal elements (Table 2) were observable and exhibited pathological changes. Enlargement of the sternal ends of the ribs and new bone formation in the orbits were only considered as possible evidence of scurvy if there were other related changes in the skeleton. The criteria were set according to clinical (Barlow, 1883: 168, Melikian and Waldron, 2003) and palaeopathological observations (Brickley and Ives, 2006, Lewis, 2004, Ortner and Ericksen, 1997).

Table 2. Skeletal elements observed for evidence of vitamin C and D deficiencies.

ADULTS		
Vitamin C deficiency		
Skeletal element	**Changes**	**References**
Orbits, leg bones	Bilateral new bone formation	Fain, 2005, Sloan et al., 1999, Wolbach and Howe, 1926
Ribs	Transverse fractures adjacent to costochondral junction	Aschoff and Koch, 1919: 53, Maat, 2004, Sloan et al., 1999, van der Merwe et al., 2010
Maxilla and mandible*	Periodontal disease	Touyz, 1997, van der Merwe et al., 2010
Residual vitamin D deficiency (childhood rickets)		
Pelvis, arm and leg bones	Deformities, abnormal angulation	Brickley et al., 2005, Hess, 1930, Ortner, 2003: 394-8, Pettifor and Daniels, 1997
Active vitamin D deficiency (osteomalacia)		
Skull	Fine porosity and “cardboard-like” consistency of the bones	Mankin, 1974, Ortner, 2003: 398, Pitt, 1988
Pelvis, ribs, all long bones, scapulae	Deformities, fractures, pseudo-fractures	Brickley et al., 2005, 2007, Hess, 1930, Schamall et al., 2003
NON-ADULTS		
Vitamin C deficiency (scurvy)		
Orbits Arm bones, leg bones**	New bone formation	Brickley and Ives, 2006, Ortner, 2003: 384-93, Ortner and Ericksen, 1997, Ortner et al., 1999
Skull vault (internal and external), greater wing of sphenoid, inferior aspect of ascending ramus of mandible, infraorbital foramen of maxilla, supra- and infra-spinous fossae of scapulae	New bone formation and/or abnormal porosity	
Ribs	Fracture or enlargement adjacent to the costochondral junction	
Vitamin D deficiency (rickets)		
Orbits, ectocranial skull vault	New bone formation and/or abnormal porosity; delayed closure of the fontanelles	Hess, 1930, Ortner, 2003: 394, Pettifor, 2003
Ribs	Enlargement at the sternal ends	Hess, 1930, Mays et al., 2006, Ortner and Mays, 1998, Pettifor, 2003, Pommer, 1885
Long bones	Abnormal bowing of the shaft and flaring of metaphyses; abnormal porosity on growth plates; deposition of osteoid	

*-only if co-occurring with bilateral lesions on long bones of legs; **Bilateral

Lesions occurring bilaterally on the long bones of the arms and legs in children with related skull and/or post-cranial lesions were considered as possible evidence of scurvy (Stark, 2014), but other specific and non-specific conditions were considered (see Discussion). A note was made on whether the bilateral lesions were symmetrical, i.e. affecting the same aspect, or aspects, of the bones, as symmetrical lesions are characteristic in living patients with the condition (Golriz et al., 2017, Gupta et al., 1989, Nerubay and Pilderwasser, 1984). If new bone formation on a long bone of an arm and/or leg was consistent with a possible healed or healing fracture, the involved element(s) was/were classed as not observable for analysis of possible vitamin C and D deficiencies.

Since juvenile scurvy can affect new-born babies if the mother has been malnourished (Hirsch et al., 1976, Ortner, 2003: 384), non-adult individuals of all ages were studied for possible abnormal cranial and post-cranial bone reaction. The analysis of very young individuals was aided by comparison of infants of a similar age to avoid recording developmental (age related) bone changes as pathological (Lewis 2017: 3).

For active vitamin D deficiency to be classed as present in children, the main criteria were skeletal deformities and deposition of osteoid in long bones and specific changes in ribs (Table 2); lesions on the skull were considered as additional evidence (Ortner, 2003: 394). Healed, or residual, rickets in adults was classed as present if bowing deformities were present in long bones, particularly of the legs, but also of the arms, and the pelvis (Table 2). For evidence of active vitamin D deficiency, or osteomalacia, in adults the bones of the skull were observed for fine porosity and a “cardboard-like” consistency; the pelvic bones, the ribs, long bones and scapulae were observed for any deformities, fractures, and pseudofractures (Table 2). Where abnormal porosity and/or periosteal lesions were observed on just one of the skeletal elements included in the study, or bilaterally on paired elements, these were classed as non-specific, and their prevalence was analysed separately (see below).

Evidence of bone changes in the form of reactive and healed new bone formation and/or porosity was recorded in the maxillary sinuses and on the visceral surfaces of the ribs in every observable individual. Maxillary sinusitis was assessed and recorded as present if abnormal porosity and/or new bone formation, active or remodelling, was present on the sinus walls or floor (Boocock et al., 1995). If there was a periapical lesion with drainage into the maxillary sinus, dental disease induced sinusitis was recorded. Both, sinusitis and rib lesions were recorded as present or absent.

Non-specific lesions on all skeletal elements were classed as present following the criteria for observation of vitamin C and D deficiencies above and recorded as present or absent in all adult and non-adult individuals. For periosteal reactions on long bones, whether the lesions were bilateral and symmetrical was noted. To obtain more detailed results, adults were divided into two age groups, young (18-30 years) and older (older than 31 year) for analysis of non-specific periosteal lesions on long bones. To investigate higher frailty, prevalence rates for lesions comprised of new woven bone versus healed, or healing, lamellar bone were analysed in all affected individuals.

Prevalence rates for all lesions were calculated for both the number of observed and affected individuals and skeletal elements. To test differences in prevalence rates between different demographic groups, chi-square tests were used for samples of five individuals or more, and two-tailed Fisher's Exact test for smaller samples, with the significance level set at 0.05, or lower. Only prevalence data by individual were used for statistical significance testing.

3. Results

3.1. Demography

A demographic profile has been published earlier (Petersone-Gordina et al., 2018), but a summary of the age at death and sex distribution for the cemetery contexts is given in Table 3.

Eighteen adults from the GC were insufficiently preserved for sex estimation, and these individuals were excluded from further analysis. Likewise, 29 males and 33 females could not be assigned an age at death; these individuals were included in all analyses, except in those addressing prevalence of non-specific periosteal reactions by age group.

Table 3. Number and percentage of individuals excavated from the St Gertrude's cemetery.

Adults																
	Young (18-30)				Older (31+)				Adult				Adult	%	**Total**
	M	%	F	%	M	%	F	%	M	%	F	%			
GC	33	13.5	27	11.0	62	25.3	55	22.4	23	9.4	27	11.0	18	7.3	245
MGs	37	19.4	34	17.8	66	34.5	42	22.0	6	3.1	6	3.1	0	0.0	191

Children										
	Prem.	%	0-4yrs	%	5-11yrs	%	12-17yrs	%		
GC	4	2.1	93	48.9	62	32.6	31	16.3		190
MGs	4	4.2	16	16.8	38	40.0	37	38.9		95
									Total	**721**

M-males; F-females; Prem.-premature

3.2 Pathological lesions in the adult population

3.2.1 Cribra orbitalia

The frequency of cribra orbitalia in the adult population was below 30% in all groups (Figure 3). It proved to be the most frequent in men buried in the GC, affecting 26.7% of observable individuals. Although males from the GC had higher prevalence by 18.4% than females from this context, the difference was not statistically significant (χ^2=3.15, p=0.076, N=82). In men and women from the mass graves, the prevalence only differed by 4.5%. For the number of affected/observed orbits, see Table S6.5 in Supplementary Material S6.

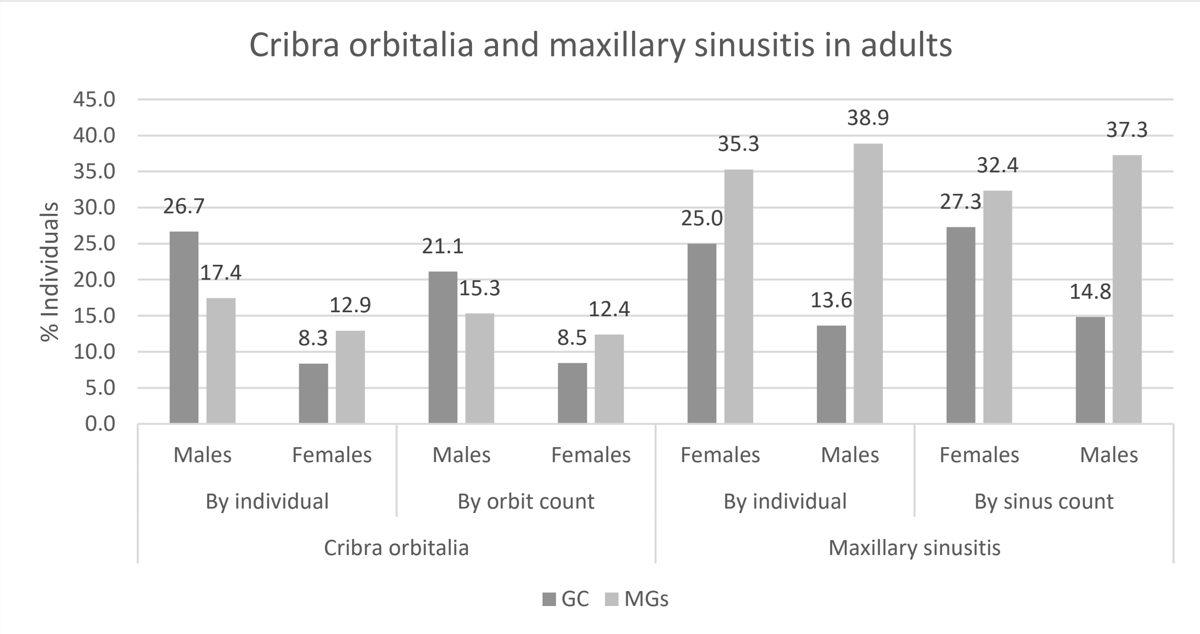

Figure 3. Prevalence of cribra orbitalia and maxillary sinusitis in the adult population.

3.2.2 Respiratory disease

Upper (maxillary) respiratory tract disorders affected between 13.6% and 38.9% observable individuals (Figure 3). Although more women than men were affected in the GC, the difference was not statistically significant (Fisher's Exact test, p=0.640, N=35). Likewise, the difference between males from both contexts was 25.5%, but this was not statistically significant (χ^2=2.2; p=0.138, N=65). The sample size was small, because most skulls were intact, thus making the observation of maxillary sinuses impossible (for the number of observed/affected individuals and sinuses, see Table S6.5 in Supplementary Material S6).

With regard to evidence for lower respiratory tract infections, visceral surface rib lesions were only observed in two adult individuals. Slight woven bone was present on two right ribs from a 40-50-year-old woman from the GC (GC_285), and one rib from a 35-45-year-old man from the MG1 (MG1_565) had a small patch of woven bone. Individual GC_285 also had lesions in the maxillary sinuses.

3.2.3 Linear enamel hypoplasia

Linear enamel hypoplasia (LEH) affected over 60% of male and female individuals in both contexts (Figure 4) and, overall, the prevalence did not differ between any groups.

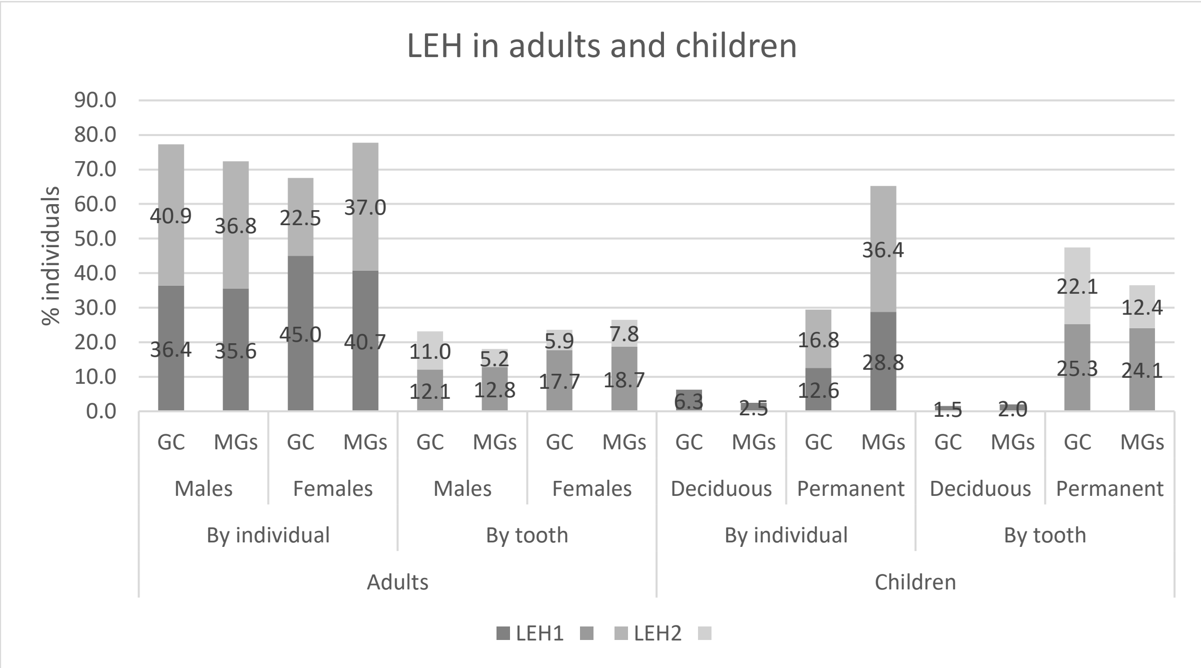

Figure 4. Prevalence of single and multiple LEH in adults and children; the percentages are given on the bars.

Analysis according to the severity of defects revealed that men from both contexts, and women from the MGs had an equally distributed prevalence of single and multiple enamel defects. In females from the GC, there were fewer multiple rather than single defects (22.5% and 45.0%, respectively). This was significantly less than in males from the GC and the MGs (χ^2=4.64, p=0.031 and χ^2=5.26, p=0.022), but not the females from the MGs (χ^2=3.33, p=0.068). The number of observed/ affected individuals and teeth for this analysis is given in Table S6.6 (Supplementary Material S6).

There were no significant differences in individuals with either cribra orbitalia or LEH, and people who had both lesions, between the GC and the MGs (11 of 70 and 14 of 118, respectively; $\chi^2=0.19$, $p=0.663$, $N=213$).

3.2.4 Vitamin C deficiency

The data on scurvy in the adult population were inconclusive. None of the adult individuals had new bone formation in the orbits, or rib fractures close to the costochondral junction. The prevalence of bilateral new bone formation on the long bones of the legs, however, was relatively high in individuals from both the GC and the MGs (Figure 5). Due to the lack of other related skeletal changes, bilateral periosteal lesions were thus classed as non-specific (not caused by a specific condition, but representative of ongoing infections and/or metabolic diseases, or other pathological conditions that precipitate an inflammatory response).

Previously acquired data on periodontal disease showed that there were no statistically significant differences in prevalence between any groups from the St Gertrude's cemetery population, and that it affected less than 50% of the people (Petersone-Gordina et al., 2018). In individuals with both at least one observable pair of long bones of the legs and teeth preserved, co-occurrence of both lesions was equally distributed, and the prevalence was below 20% in most groups (Table S6.7, Supplementary Material S6).

The number of observed orbits and ribs for this analysis can be found in Table S6.15, Supplementary Material S6.

3.2.5 Non-specific periosteal reactions

Non-specific periosteal reactions were mostly observed on the long bones of the legs, and most of these were bilateral and symmetrical (Figure 6). The prevalence of woven bone in the affected individuals was under 20% in both men and women (see Table S6.8 in Supplementary Material S6). While the lesions were equally distributed in females from the GC and the MGs (12.1 and 7.7%, respectively), there were significantly more males affected in the GC, compared to the MGs (21.4% and 3.6%, respectively, Fisher's Exact test, $p=0.006$, $N=64$).

Periosteal reactions on femora affected younger individuals and men from mass graves more frequently than other demographic groups (Figure 5). Young women from the MGs had a significantly higher prevalence of femoral lesions than older women from this context (Fisher's Exact test, N=64, p=0.006). Older males from mass graves had a significantly higher prevalence of lesions on femora than older males from the GC (χ^2=4.17, p=0.041, N=108), while the difference was not significant in younger males (χ^2=3.23, p=0.072, N=52). The lesions on the tibiae had the highest prevalence in all age and sex groups. The number of affected individuals and long bones for this analysis is given in Table S6.9 in Supplementary Material S6.

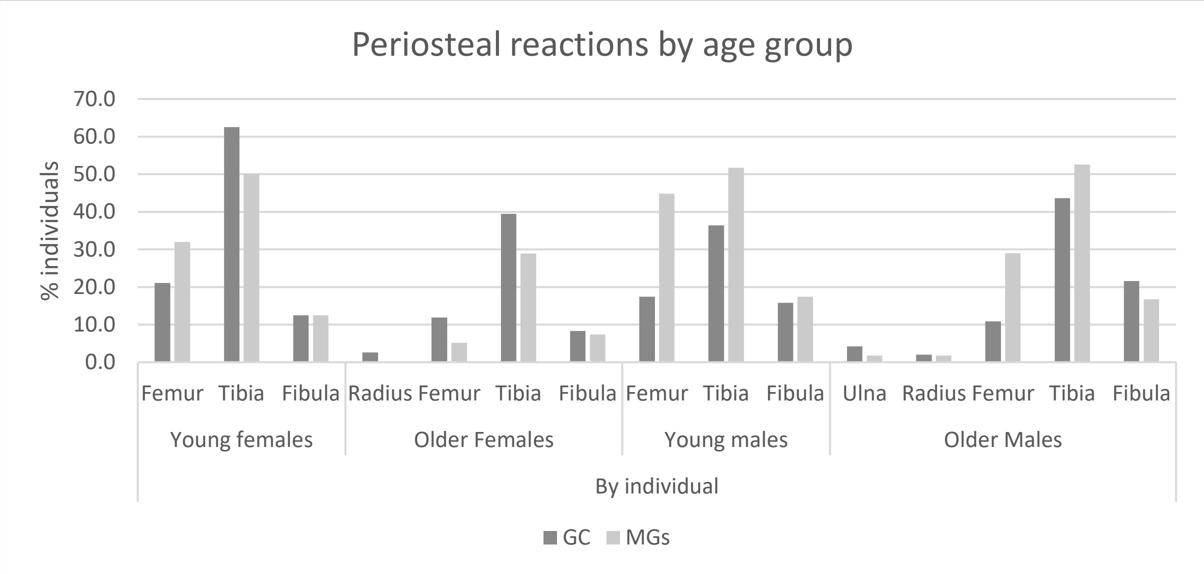

Figure 5. Prevalence of non-specific periosteal reactions by age group.

Bilateral periosteal reactions on the femora affected less than 15% of women from both contexts, and all lesions were symmetrical (Figure 6). The prevalence of lesions on the tibiae was twice as high as on female femora from both contexts, and most lesions were also symmetrical. The prevalence of new bone formation on fibulae was 8.2% higher in females from the MGs than the GC. All lesions (3.2%) on female fibulae from the GC were asymmetrical, while most lesions (8.6%) were symmetrical in people from the MGs.

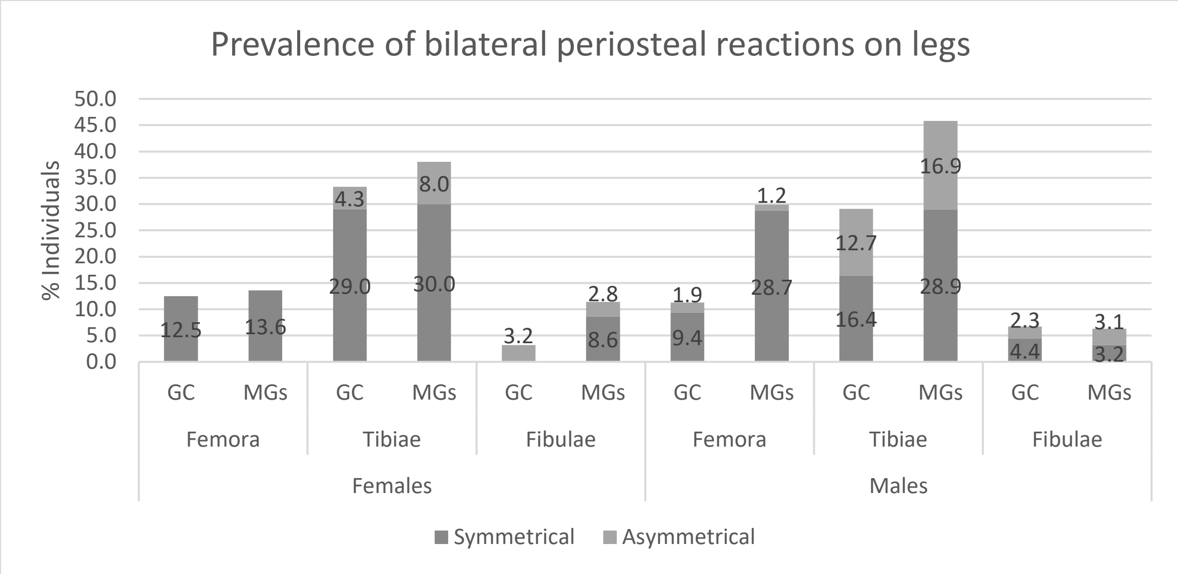

Figure 6. Prevalence of bilateral and symmetrical/asymmetrical periosteal reactions on the long bones of legs in the adult population.

In men from the MGs, the prevalence of bilateral new bone formation on femora and tibiae was considerably higher, compared to men from the GC, while the distribution of asymmetrical lesions was largely similar in both groups. The difference in prevalence of femoral lesions proved to be significant (χ^2=5.43, p=0.020, N=140), but the difference in lesion frequency on tibiae was not (χ^2=3.2, p=0.074, N=138). The fibulae were affected in less than 10% of men from both contexts, and the distribution of symmetrical and asymmetrical lesions was similar for this skeletal element. The number of affected individuals and long bones for this analysis is given in Table S6.10 in Supplementary Material S6.

3.2.6 Residual rickets

Slight bowing deformities on the long bones of arms and/or legs were observed in 38 individuals (15 from the GC and 23 from the MGs). In most people, the deformities were only observed on the long bones of legs (Table 4). The femora were bowed antero-posteriorly at the proximal 1/3 of the shaft in most individuals, while on the tibiae lateral bowing of the proximal 1/3 of the shaft was observed. The long bones of the arms were only affected in people from the GC. The long bones of the legs, especially the femora and tibiae, were affected in individuals of both sexes from both contexts. No differences between any groups were statistically significant. For the number of observed/affected long bones, see Table S6.11 in Supplementary Material S6.

Table 4. Prevalence of individuals with slight bowing deformities.

	Context	Radius	%	Ulna	%	Femur	%	Tibia	%	Fibula	%
Females	GC	1/64	1.6	1/68	1.5	3/70	4.3	4/74	5.4	2/70	2.9
	MGs	0/62	0.0	0/63	0.0	3/67	4.5	5/58	8.6	0/46	0.0
Males	GC	3/74	3.9	3/73	4.1	4/80	5.0	5/75	6.6	2/68	2.9
	MGs	0/91	0.0	0/92	0.0	9/92	9.8	10/87	11.5	3/75	4.0

3.3 Pathological lesions in the non-adult population

3.3.1 Cribra orbitalia

Cribra orbitalia, or orbital porosity, was observed in 34 of 93 children from the GC (36.6%) and 33 of 67 children from the MGs (49.3%). All the observed lesions were healed. The prevalence of cribra orbitalia by orbit count was very similar for both contexts (39.3% and 49.2%, respectively). Although more children from the mass graves were affected, the difference between the groups was not statistically significant (χ^2=2.08 p=0.149, N=160). The number of affected/observed orbits is given in Table S6.5 in Supplementary Material S6.

3.3.2 Linear enamel hypoplasia

In non-adult individuals, LEH affected both deciduous and permanent teeth. Although it was more prevalent in permanent dentitions, six children from the GC and one from the MGs had single defects on deciduous teeth (Figure 4, Section 3.2.3 above). With regard to permanent teeth, LEH was 35.8% more prevalent in children from MGs than the GC. The difference in overall prevalence between the two contexts was statistically significant (χ^2=18.69, p<0.001, N=161). There were slightly more non-adult individuals with multiple rather than single enamel defects on each affected tooth in both contexts. The number of observed/ affected individuals and teeth for this analysis is given in Table S6.12 (Supplementary Material S6).

When comparing children who had either cribra orbitalia, or LEH, to individuals with both conditions, it emerged that there were significantly more children with both lesions in the MGs, compared to the GC (19 of 54 and four of 47, respectively, χ^2=8.71, p=0.003, N=101).

3.3.3 Vitamin C deficiency

Eight of 163 observable children (4.9%) from the GC had pathological changes in the skeleton possibly resulting from scurvy. In two of these individuals, evidence for vitamin D deficiency was also observed (Table 5, Figure 7). Five of these children had abnormal porosity and/or new bone formation in the orbits, while new bone formation on the bones of the skull vault was only observed in three children. Pathological changes around the infra-orbital foramina were observed in five non-adults, but the ascending ramus of the mandible was only affected in one child. The greater wing of the sphenoid bone exhibited porosity in six children, but the element was not observable for two individuals.

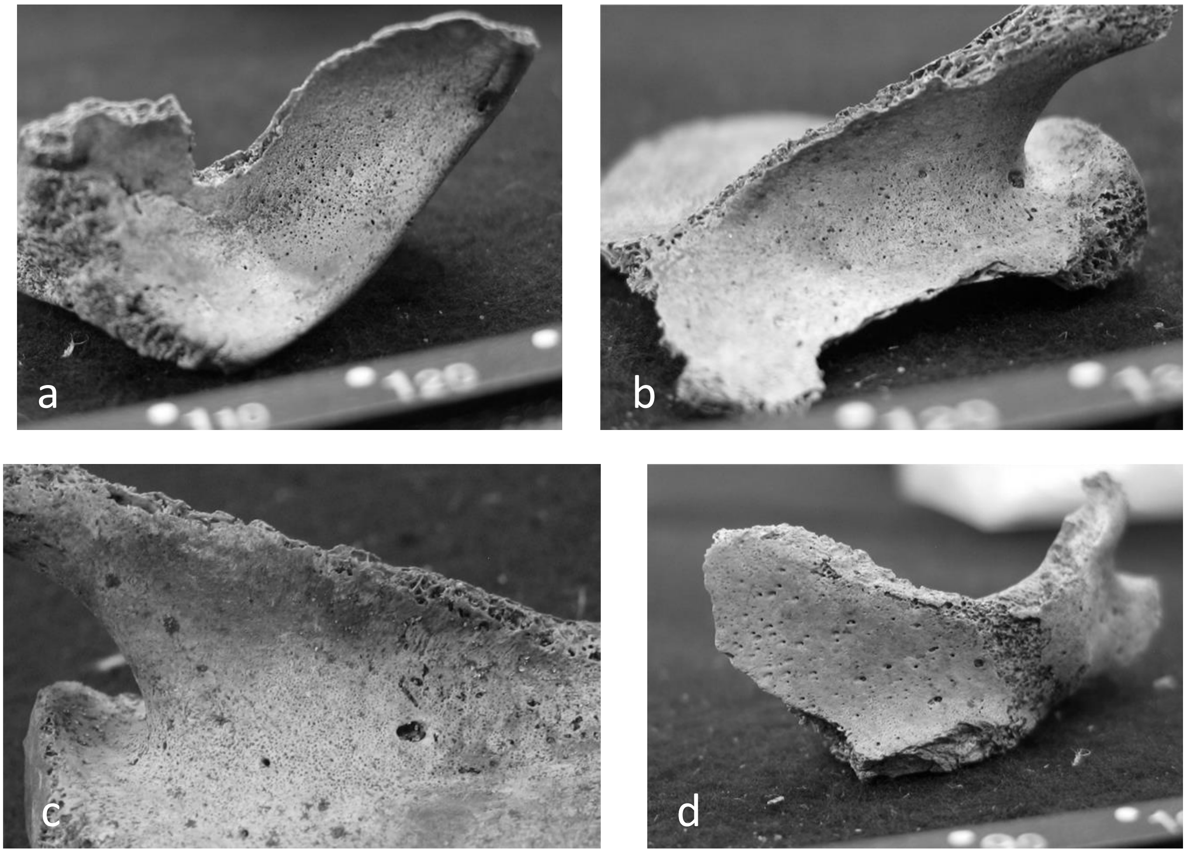

Figure 7. Abnormal porosity and new woven bone in the orbit (a), supra-spinous fossa of the scapula (b), infra-spinous fossa of the scapula (c), and abnormal porosity on the greater wing of sphenoid (d) in individual GC_192.

Likewise, the infra- or supra-spinous fossae of the scapula were affected in seven children, and pathological changes were only absent in one. While bilateral and symmetrical new bone formation on the long bones of arms was only observed in one individual, similar pathological lesions on the leg bones were seen in all six children where the relevant skeletal elements were preserved. None of the 88 observable children from the MGs had pathological changes possibly related to scurvy in their skeleton. For the number of affected/observed skeletal elements, see Table S6.13 in Supplementary Material S6.

3.3.4 Vitamin D deficiency

In a further five of 175 observable children from the GC, and one of 90 observable children from the MGs (MG1_438), pathological changes possibly caused by vitamin D deficiency were observed (Table 5). Of the affected children, cribra orbitalia and/or new bone formation in the orbits, were present in five of six observable individuals, but new bone formation on the skull vault only affected one of seven. Bowing deformities of the long bones of the arms were observed in one of seven children, but similar pathological changes of the long bones of the legs were present in all seven observable non-adults (Figure 8). For the number of observed/affected skeletal elements, see Table S6.13 in Supplementary Material S6.

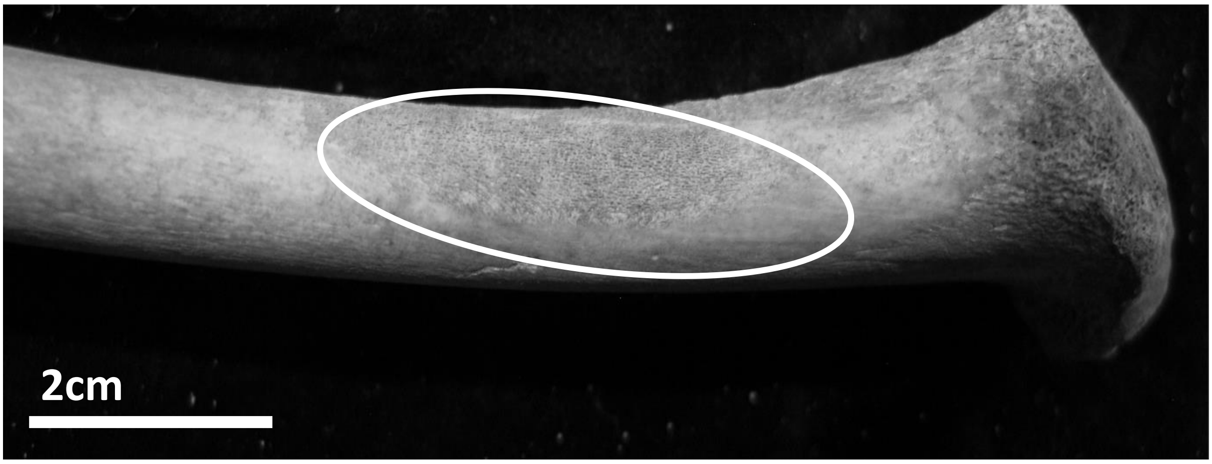

Figure 8. Femur of individual GC_209, showing a slight posterior bowing deformity at the proximal end, as well as new bone formation on the posterior shaft, consistent with the concave aspect of the deformity (circled in white).

Table 5. Presence of pathological lesions possibly related to scurvy and/or rickets.

ID	Mths	Yrs	Orbits	Cranium	IFOF	AR	GWS	I/SSF	Arms	Legs
POSSIBLE SCURVY										
GC_9		1-2	p	a	p	a	p	p	a	p
GC_32		2-3	p	a	a	n	p	p	a	p
GC_76		2-2.5	p	p	p	a	p	a	p	p
GC_192*	4-6		p	a	n	p	p	p	a	p
GC_193		1-1.5	a	p	p	a	p	p	n	n
GC_209*		1.5-2	n	n	a	a	n	p	a	p
GC_216		2-3	p	p	p	p	p	p	a	p
GC_304		2-3	a	a	p	n	n	p	n	n
POSSIBLE RICKETS										
GC_8	9-12		p	p	N/A				p	n
GC_121		1-1.5	n	n					a	p
GC_192^	4-6		p	a					a	p
GC_209^		1.5-2	n	n					a	p
GC_232		1.5-2	p	a					n	p
GC_264	9-12		p	a					p	p
GC_352	9-12		a	a					a	p
MG1_438		8-9	p	a					a	p

Notes: ID–skeleton number; mths-age in months; yrs-age in years; IFOF-infra-orbital foramen; AR-ascending ramus of the mandible; GWS-greater wing of sphenoid; I/SSF-infra-/supra-spinous fossa of the scapula; *-individuals with possible rickets; ^- individuals with possible scurvy; a-pathology absent; p-pathology present; n-element not observable.

3.3.5 Non-specific pathological changes affecting cranial and/or post-cranial elements, and respiratory disease.

There were also 53 individuals (39 from the GC and 14 from the MGs) for whom a possible diagnosis of scurvy and/or rickets could not be suggested due to the lack of a systematic pattern of bone changes usually present in these two conditions, as detailed in Table 2, but who had similar pathological lesions present in at least one of the bone elements observed in this analysis. These lesions were classed as non-specific, as already discussed above with regard to the adult population. As with possible scurvy and rickets, non-specific pathological lesions were substantially more prevalent in children from the GC than those from MGs (Figure 9).

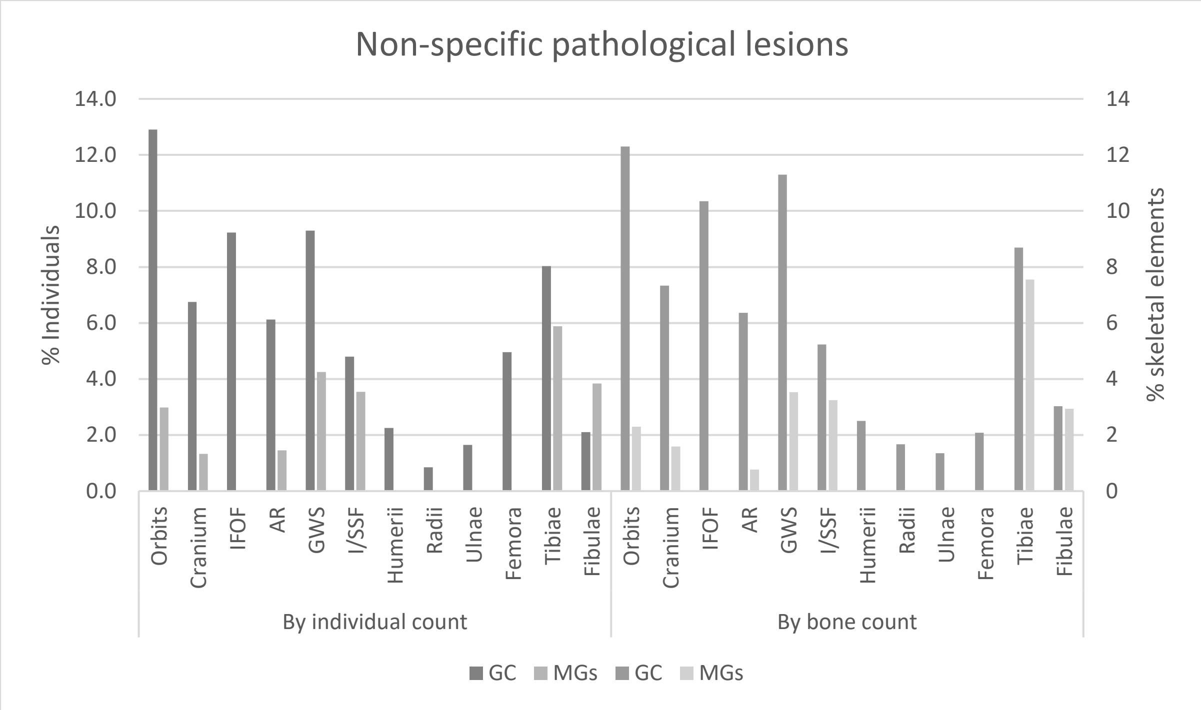

Figure 9. Non-adult individuals with non-specific pathological changes affecting cranial and/or post-cranial elements. Abbreviations: IFOF-infra-orbital foramen; AR-ascending ramus of the mandible; GWS-greater wing of sphenoid; I/SSF-infra-/supra-spinous fossa of the scapula.

The lesions in the orbits, in/on the cranium, and around the infra-orbital foramina were observed in significantly more children buried in the GC than in the MGs (Fisher's Exact test, p=0.044, N=160; χ^2=4.52, p=0.033, N=314 and Fisher's Exact test, p=0.028, N=127, respectively). Periosteal lesions on the long bones of the arms, as well as femora, were only present in children from the GC, although the prevalence was below 5%. The differences in the other skeletal elements were not statistically significant. For all observed/ affected individuals and skeletal elements for this analysis, see Table S6.14 in Supplementary Material S6.

Finally, maxillary sinusitis and visceral rib lesions were not observed in any non-adult individuals. For the number of observed maxillary sinuses and ribs, see Table S6.15 in Supplementary Material S6.

4. Discussion

The main aims of this study were to compare several aspects of physical health in people from the GC and MGs, considering that they represent different generations, and to test if people from mass graves were predisposed to higher frailty. The results have revealed several different patterns between children and adults from both contexts and will be discussed in more detail below.

This study recognises, however, that interpreting prevalence rates of pathological lesions is not straightforward. Several authors have cautioned against directly interpreting prevalence rates as indicators of poor physical health on a population level (Boldsen and Milner, 2012, DeWitte and Stojanowski, 2015, Reitsema and McIlvaine, 2014, Temple and Goodman, 2014, Wood et al., 1992). This is mainly because all such studies are biased by three key factors, as defined by Wood et al. (1992), demographic non-stationarity or the fact that populations can increase and decline over time; selective mortality, which means that not all people with potentially life-threatening conditions will die from them, and heterogeneous frailty, or a differing predisposition of particular age and/or sex groups, or individuals, to disease and, consequently, premature death. Likewise, selective mortality and heterogeneous frailty are relevant when interpreting pathological lesions which formed over a longer period and had healed at the time of death (i.e. chronic) – including cribra orbitalia and LEH, considered here. This is because the presence of these lesions suggests that the individual could survive the conditions causing them, and may thus actually represent healthier, or stronger, individuals, as opposed to people without these lesions, who could have died from the same, or similar conditions, soon after becoming affected (Ortner, 1991). This phenomenon is called the “osteological paradox”, whereby the presence or absence of certain pathological lesions in an individual cannot be directly interpreted as evidence for poor or good physical health, respectively (Wood et al., 1992). These factors will be considered throughout the Discussion.

4.1 Cribra orbitalia and LEH

Evidence for compromised childhood physical health, as expressed in cribra orbitalia and LEH, differed by context and by age group (children and adults). The lack of significant differences in the prevalence of porotic lesions in orbits in children and adults from different contexts suggests that these groups were exposed to similar living conditions and/or pathogen load. Although rejecting both hypotheses, this might be explained by the complex aetiology of the lesions, as already outlined in Section 1.2 above. With regard to the link between cribra orbitalia and acquired anaemia in this population, porotic lesions on the skull vault, which could be linked to porotic hyperostosis, possibly signalling of bone marrow hyperplasia in anaemia, were not present in any individual. A radiographic analysis would be necessary to examine the skulls with cribra orbitalia, to exclude the possibility of bone marrow hyperplasia, as expressed in thickening of the diploic space, and/or “hair on end” appearance of trabeculae (Stuart-Macadam, 1985, 1992) and, consequently, anaemia, in these individuals.

The fact that the prevalence was significantly higher in children than in adults in both contexts might indicate a degree of heterogeneous frailty, whereby children who had experienced health conditions causing cribra orbitalia were more susceptible to further episodes compromising their physical health in later childhood, such as food shortages and/or acute illnesses (Wood et al., 1992). The turbulent political situation discussed in Section 1.1 above, as well as historical and isotopic evidence for famine in this population, point to potentially inconsistent access to resources, which would have weakened the children’s resistance to diseases. Modern data from developing countries suggests that malnutrition directly leads to diarrhoeal diseases, measles, malaria and lower respiratory infections in 50-70% of children, because it considerably weakens the immune system even in milder forms (De Onis and Blössner, 2003, WHO, 2002a, You et al., 2015). This possibility will be further explored below, with regards to prevalence of LEH.

The differences in LEH prevalence were more expressed in this population. While in adults, LEH only differed in severity rather than overall prevalence, in children, significantly more individuals were affected from the MGs. It can be argued that the low prevalence rates of LEH in children from the GC indicate that many were not born strong enough to survive episodes of arrested growth in the first years of life, and thus died before developing enamel defects. Modern clinical studies have indicated that there is a link between nutritional stress of the mother during pregnancy, and poor health, or death, of her new-born child (Abu-Saad and Fraser, 2010). On the other hand, this would potentially result in a high prevalence of LEH on deciduous teeth (Hillson, 1996: 166), which was not the case in children from the GC.

Conversely, people from the MGs represent a unique group of individuals who all lived, and died, almost simultaneously. Moreover, as already discussed with regard to cribra orbitalia, these children might have had higher frailty; this would be even more true for children who had previously experienced more than one episode of compromised physical health, as also supported by the fact that there were significantly more children with both cribra orbitalia and LEH in the MGs compared to the GC. Likewise, results of incremental dentine analysis suggested that most of the 19 children whose dietary profiles were indicative of nutritional stress during their lives, were excavated from one of the mass graves (Petersone-Gordina et al., Forthcoming (a)). A recent study on famine victims from the medieval London cemetery of St Mary Spital also found significant differences with regard to the prevalence of LEH in victims of famine compared to those buried in the rest of the cemetery, albeit in all age groups rather than children, while no significant differences were observed with regard to CO (Yaussy et al., 2016). Evidence for higher frailty was also observed in a study of the victims of the 14th century Black Death in London, whereby older individuals, and those with previous episodes of compromised childhood health (LEH and CO), as well as active inflammation on tibiae, were more likely to die from the infection (DeWitte, 2009, DeWitte and Hughes-Morey, 2012, DeWitte and Wood, 2008).

If heterogeneous frailty did indeed influence the risk of early mortality in children from mass graves, then the high number of individuals with LEH is not representative of the actual prevalence. The equal number of adults affected in both contexts, supports this possibility. On the other hand, the significantly lower prevalence of multiple lesions in women from the GC, compared to men from the GC and MGs, might point to differential breastfeeding and weaning practices, and/or differences in early childhood diet for boys and girls. So far, this is not supported by carbon and nitrogen incremental dentine data, but this inference is tentative due to the small study sample size, as well as a current lack of data about the sex of these children. The existing evidence, however, suggests a high level of uniformity in terms of childhood diet for this population group (Petersone-Gordina et al., Forthcoming (a)). Alternatively, it is possible that boys were more susceptible to nutritional and physiological stress associated with early childhood diet – modern clinical data suggests that boys have a less pronounced immune response to infection and other physiological stress factors than girls (Eveleth and Tanner, 1990, Grossman, 1985: 257, Kuh et al., 1991, Ortner, 1998, Talal, 1992); moreover, some data suggests that the differential immune response of the two sexes continues into adulthood, although it does depend on age (Klein and Flanagan, 2016, vom Steeg and Klein, 2016).

4.2 Maxillary sinusitis

The lack of statistically significant differences in the prevalence of maxillary sinusitis in adults between contexts, suggests that the individuals from the GC and the MGs faced similar everyday living/working conditions. This is not surprising, given that most people buried in the cemetery were farmers, as discussed above in Section 1.1, which would have involved working in enclosed spaces with poor air quality, such as inside farm buildings, especially during the winter, or in seasonal crop harvesting and processing during the summer (Merķelis, 1999: originally written in 1796).

Upper and lower respiratory tract infections, as expressed in sinusitis and/or new bone deposits on ribs, might also have been exacerbated by particulate pollution in domestic environments (Maran, 2012), since most farmsteads in post-medieval Latvia were powered by firewood. Historical evidence points to heavy smoke induced pollution in the homes of poorer farmers, where there was a single central room with a hearth, with no chimney and windows for ventilation, and numerous wood splinters used for lighting, as these were considerably cheaper than candles (Merķelis, 1999: Chapter 1). This is also supported by ethnographic evidence, whereby some homes in Vidzeme built in the 18th and 19th centuries still had so-called “black” kitchens, which were mainly used for preparing food for farm animals. Hearths had no chimney but, instead, a small hole in the wall was made for the smoke to escape (Figure 10). Death from illnesses caused by poor indoor air quality, such as childhood pneumonia, “stroke” and ischemic heart disease, is still a major problem today in African and Asian countries, where the main source of energy in the home are open fires. Although women and young children, who spend most of their time around the hearth, are most exposed to health risks caused by household air pollution in living populations (WHO, 2005, 2016a, 2016c), no evidence for respiratory disease was found in children buried in St Gertrude’s cemetery, thus suggesting different practices in this population.

To explore sinusitis prevalence further, all individuals with intact sinuses would have to be observed for evidence of sinusitis, with the help of an endoscope; this was beyond the scope of this study. Moreover, comparative data from other contemporary urban and rural cemeteries would reveal any trends present between the population groups.

Figure 10. Example of a “black” kitchen, showing a wood burning stove (left), and a small hole in the back wall for the smoke to escape.

4.3 Vitamin C and D deficiencies

4.3.1 Children

In the St Gertrude’s cemetery population, probable evidence for active scurvy and vitamin D deficiency was only found in non-adult individuals. The fact that all except one affected child came from the GC might be partly due to the uneven age distribution of individuals in both contexts. Notably, there were few children aged between birth and four years in the MGs, but all children with probable scurvy and/or rickets from the GC were in this age group. The higher prevalence of both conditions in children within this age group is also supported by historical evidence, whereby infantile scurvy has mostly been observed in children between four and 10 months of age (Wimberger, 1925: 288-307), and rickets in non-adults aged from four months to four years (Hess, 1921, Schmorl, 1909: 437). It is therefore possible that young children were buried elsewhere in the cemetery or in individual graves, even during the mass mortality event which affected the population, thus skewing the prevalence rate of these conditions in non-adults from mass graves. On the other hand, it is possible that children who were buried in the MGs did experience either one, or both conditions; but that they died before developing any lesions (Wood et al., 1992). This would be particularly true for the children who experienced the famine, as shown by the incremental dentine analysis (Petersone-Gordina et al., Forthcoming (a)).

The presence of scurvy in the territory of Latvia in the past is mentioned in historical sources, which state that the disease affected all social classes (Amelung, 1885). Evidence for the disease in the St Gertrude's cemetery, as well as another recent bioarchaeological study, seems to support these historical data; both scurvy and rickets were diagnosed in several non-adult individuals from a wealthy post-medieval German population buried in a cemetery in the city of Jelgava (shown on the map in Figure 1) (Pētersone-Gordina et al., 2013). This is disregarding skeletons excavated form archaeological sites who may have died before the bone changes were manifest (Wood et al., 1992).

Vitamin C is mainly present in vegetables and fruit (Kiple and Ornelas, 2000: 231-358, Weinstein et al., 2001), but its role in diet only came to be understood by the end of the 18th century (Hughes, 1990: 53). Before then, the disease commonly affected populations where foods containing vitamin C were not available due to famines or conflict, as well as environmental conditions, such as prolonged winters (Carpenter, 1986, 1987, Crellin, 2000, Ortner, 2003: 384). In Latvian history, scurvy might have been more prevalent in winter, especially when the stock of vegetables with good storage properties, such as carrots and cabbages, would be depleted towards the arrival of spring; likewise, during famines and warfare, which caused general food shortages, vitamin C deficiency would have also been commonplace. Given the turbulent political situation in the post-medieval period, it is likely that almost every generation of the St Gertrude's population would have experienced such hardships and, consequently, scurvy. Nowadays, scurvy still poses a risk for uncared for older people, as well as people who have alcohol or drug addictions, and children with neuropsychiatric and developmental disorders (Agarwal et al., 2015, Weinstein et al., 2001).

Rickets became a serious health issue during the industrialisation of Europe, and was mostly limited to cities and towns, where high and narrow buildings, or long working hours in factories prevented adequate exposure to sunlight (Rajakumar, 2003). While vitamin D deficiency is still known to affect people in countries with short summer seasons, and/or populations living in northern latitudes (Palaniswamy et al., 2017, Webb et al., 1988), it is also prevalent in regions where sunshine is abundant. However cultural practices, especially extensive covering of the skin outdoors with clothing, prevent the natural synthesis of vitamin D (Al-Daghri et al., 2017). Ethnological evidence suggests that in the general population of post-medieval Latvia, and Riga in particular, it was not customary to limit exposure of the skin through wearing extensive clothing, particularly for children, during the summer (Brotze, 1992). Although rickets was observed in several children from this population, the subtle appearance of the lesions suggests that it was not a serious health issue.

4.3.2 Adults

Evidence for residual rickets in adults might help shed light on its prevalence in populations from both contexts, given that the prevalence of the condition in the MGs might have been influenced by the lack of children of certain age groups, as discussed above. Indeed, possible residual rickets had equal prevalence in adults from both contexts. Taking into account that most of these people were subsistence farmers, and likely spent much of their time outdoors, the finding is intriguing; when found in skeletal populations from rural contexts, the disease has been interpreted as resulting from cultural practices, or prolonged illness, since in rural areas people are thought to have had adequate exposure to sunlight (Ortner and Mays, 1998, Veselka et al., 2015). While prolonged illness remains a plausible cause for the St Gertrude's cemetery population, it is also possible that many children spent the coldest winter months indoors, which resulted in seasonal lack of vitamin D. Combined with a diet which provided little vitamin D (Holick 2007), it is plausible that some children began to develop characteristic bone changes. The fact that vitamin D deficiency was not a major problem in the St Gertrude's cemetery population, however, is supported by the lack of osteomalacia in adult individuals.

With regard to vitamin C deficiency, in adults, periodontal disease and bilateral periosteal lesions on the long bones of the legs only co-occurred in under 18% of individuals (29 of 162), while the prevalence of bilateral lesions on the leg bones was higher in all groups. In archaeological human remains, a diagnosis of adult scurvy can be based on skeletal lesions which include possible reactions to subperiosteal bleeding into the tissues, ultimately affecting the long bones, and periodontal disease. This was observed in a study involving the remains of Dutch whalers, who were known to have been experiencing severe vitamin C deficiency at the time of their death (Maat, 1982, 2004, van der Merwe et al., 2010). Neither the co-occurrence of periodontal disease and bilateral periosteal lesions, nor the presence of periosteal reactions alone, however, can be classed as reliable evidence for scurvy. This is because periosteal reactions can be caused by various other conditions (see Section 1.2 above), while periodontal disease, which causes porous appearance of the alveolar bone, is primarily caused by bacteria in dental plaque (Touyz, 1997). Moreover, recent research suggests that the presence and distribution of periosteal reactions on particular skeletal elements in people known to have experienced specific diseases, including scurvy, are subject to considerable individual variation, which makes a diagnosis in archaeological populations even more difficult (Weston, 2008, 2009, 2012).

Based on the current evidence, it is possible that some individuals with periodontal disease and bilateral periosteal reactions, as well as those with new bone formation on both legs, did have scurvy; on the other hand, the lack of severe lesions, such as rib fractures, and the low prevalence of the disease in children, suggests that vitamin C deficiency was not a serious health problem in this population. Further developments in diagnosing adult scurvy in archaeological populations might alter the current prevalence of scurvy in adults from this cemetery.

4.4 Non-specific pathological lesions

The higher prevalence of non-specific lesions in children from the GC, compared to individuals from the MGs, is consistent with the prevalence of rickets and scurvy in the non-adult population. The cause of these lesions might have differed from individual to individual and included infections, trauma, or milder, and/or healed, bone changes due to vitamin deficiencies, discussed above. The significantly higher prevalence rates of pathological changes in the orbits and around the infra-orbital foramina of children from the GC indicate that these might have been the most frequently involved skeletal elements, or that the remodelling process was longer (where the changes manifested themselves as abnormal porosity). The relatively low prevalence of non-specific lesions in children compared to adults might be because systemic conditions are likely to involve other skeletal elements in most children (Ortner, 2003: 383-98). Thus, a specific disease may be a possible cause.

In adults, almost all observed lesions in this study were classed as non-specific, due to the number of conditions which can lead to them, as outlined in Section 1.2 above, and most were limited to the long bones of the legs. The relatively high prevalence of bilateral and symmetrical lesions suggests a possible systemic disorder in at least several individuals, although it is not clear if vitamin C deficiency might be among the possible causes. With regard to heterogeneous frailty, DeWitte and Stojanowski (2015) suggested that active lesions in skeletal remains might indicate higher frailty and earlier mortality in the affected individuals. The low prevalence of woven new bone lesions in adults from mass graves does not support these findings, unlike the observed link between multiple episodes of compromised health in childhood and a higher risk of mortality in children from the MGs. On the other hand, the prevalence of periosteal lesions was also significantly higher in people from attritional rather than famine burials in the cemetery of St Mary Spital in London, discussed above with regard to LEH. The authors interpreted the difference as evidence for the ‘Osteological Paradox’ (Wood et al., 1992), whereby during food shortages people who developed conditions which cause bone apposition on upper or lower extremities were less likely to survive, and died before the lesions could develop, in contrast with periods of adequate nutrition (Yaussy et al., 2016). This might have been the case for people from St Gertrude’s cemetery population too.

The significantly higher prevalence of periosteal lesions in younger individuals, and men buried in MGs, suggests that some aspects of living/working conditions for younger and older men and women were different in both populations, thus partly supporting both hypotheses of this study. Young people in general, and older males from mass graves, were more likely to experience conditions which caused new bone formation on femora. On the other hand, this finding also suggests that both populations were equally exposed to similar physical health risks. In order to better understand the prevalence of periosteal lesions in this population, comparative data from other contemporary urban and rural cemeteries in Latvia would be necessary. Future studies on skeletal populations from Latvia, as well as advances in understanding the aetiology of periosteal reactions on long bones, might help to better explain the distribution of them in the St Gertrude’s cemetery population.

5. Conclusions

This study has generated enough evidence to suggest that many aspects of the living and/or working environment were similar for children, men and women buried in the GC and MGs. This resulted in similar prevalence rates for several pathological conditions, including maxillary sinusitis, cribra orbitalia, and LEH, especially in adults, and partly rejects both hypotheses of this study. Where differences between the two populations were observed, they were complex, and indicated that age (younger versus older adults, and adults versus children) and sex (men versus women) might have been important factors for the morbidity differences seen in both populations. On the other hand, differences in prevalence rates of certain pathological conditions in children, particularly those related to compromised childhood health, were suggestive of a higher risk of mortality for children in the mass graves, which fully supports the second part of hypothesis 2, and also complements previously published studies on frailty of specific individuals during mass mortality events, particularly famine.

The research has met its main aims, but it has also generated a wealth of comparable data from Latvia, together with the other three papers based on this population. This is a valuable addition to the currently scarce bioarchaeological data from Latvia and offers a comprehensive base for future local as well as Eastern European and Baltic bioarchaeological studies.

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Chapter 8. Manuscript 5.

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Oral health, evidence for compromised physical health in childhood, and adult stature reflected in the people buried in the post-medieval St Gertrude Church cemetery, Riga, Latvia (15^{th}-17^{th} century AD), and contemporary cemetery populations from Latvia, Lithuania and Estonia

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Key words: Caries, periapical lesions, ante-mortem tooth loss, linear enamel hypoplasia, cribra orbitalia, adult stature, Baltic States

Abstract

This study compares data on dental disease (caries, periapical lesions, and ante-mortem tooth loss), evidence for compromised physical health in childhood (linear enamel hypoplasia and cribra orbitalia) and adult stature in the skeletons of people from St Gertrude Church cemetery, Riga, Latvia and 20 contemporary cemetery populations from Latvia, Lithuania and Estonia. Due to different methods used for recording and data presentation in the comparative populations, it was not possible to compare certain pathological lesions by sex and/or age groups, and comparison of stature estimates was only possible for cemetery populations from Latvia.

There were significantly higher caries rates in women from one high-status group, compared to those from St Gertrude's cemetery. No statistically significant differences in the prevalence of periapical lesions and antemortem tooth loss were observed. Comparison of linear enamel hypoplasia and cribra orbitalia did not demonstrate any link with social status, or urban and rural living environments, suggesting that pathogen load and access to resources differed within each community, and was likely dependent on local availability. Linear enamel hypoplasia affected most of the observed adults, while cribra orbitalia was

more prevalent in children. Stature estimates showed that men in high-status groups were significantly taller than those buried in St Gertrude's cemetery, but women were not, suggesting that social status was not the only factor in defining adult stature in the observed groups.

1. Introduction

This study compares data on dental disease (caries, periapical lesions, and antemortem tooth loss) and evidence for compromised physical health in childhood (linear enamel hypoplasia and cribra orbitalia) in people who were buried in St Gertrude Church cemetery in Riga, Latvia, with broadly contemporary post-medieval cemetery populations from Latvia, Lithuania and Estonia. A series of bioarchaeological data were previously gathered from skeletons excavated from the three contexts of the cemetery, the general cemetery, and two mass graves, as a part of a larger research project (see below). This study aims to place the St Gertrude's cemetery population in a regional context, by comparing possible differences in diet and certain aspects of physical health in populations with different social statuses (low-moderate, and high) and living environment (urban and rural). Although the prevalence of certain pathological lesions, as well as other bioarchaeological data have been compared between cemetery populations in the region, a wider study, including several markers of health and well-being has not been attempted before. This study will not only provide an insight into local and regional differences in living conditions for the people who lived in the post-medieval Baltic States, but also highlight differences in recording and presenting data that can often make detailed comparative studies difficult in bioarchaeology.

Today Latvia, Lithuania and Estonia are independent countries (Figure 1), but in the post-medieval period (15th-18th centuries) different political powers were controlling the territory, resulting in differences in living conditions. In Latvia and Estonia, some cemeteries were reserved mostly for the landowning classes, which mostly comprised people of Germanic origin, while for most people their quality of life largely depended on social status and wealth. However, frequent warfare, and consequent outbreaks of famine and/or plague epidemics likely affected the population in the whole region, potentially resulting in a high prevalence of indicators on the skeleton reflecting compromised childhood health, such as cribra orbitalia and linear enamel hypoplasia. Likewise, historical data suggest that bread and other cereal grain-based foods comprised the main part of the diet for people of low and moderate status across the region, and the link between carbohydrates and destructive dental disease (e.g.

caries) might have resulted in largely similar prevalence rates for conditions such as caries, periapical lesions, and antemortem tooth loss. On the basis of what is known about Riga during this period of time, this paper tests the hypotheses that:

Figure 1. Map of the Baltic States, and the locations of all urban and rural (*in italics*) populations used in this study.

1) The prevalence of caries, periapical lesions and antemortem tooth loss in the St Gertrude's population will not be significantly different compared to people who lived in other urban and rural environments and were of a similar social status, but will be significantly higher in high-status groups, due to the availability of refined sugar;

2) The prevalence of linear enamel hypoplasia and cribra orbitalia will be higher in mass graves (MGs) and rural population groups than in the general cemetery (GC) and other urban groups, as well as high-status populations;

3) Stature estimates for people from the GC and MGs will be similar to those from other populations of low-moderate social status, but significantly lower than in high-status groups.

1.1 Historical background

St Gertrude Church was first mentioned in historical sources in 1413 and was built outside the old centre of Riga. The church was located by the main road connecting the city to the Vidzeme region, of which Riga is the capital, and further afield to Estonia and Russia (Pīrangs, 1932). The church and the cemetery around it were mainly used by people from nearby Gertrude village, who were mostly small-scale farmers. A road linked the site to St George's hospital; thus, it was likely used as the hospital's church and cemetery (Šterns, 1998). Although the native population was controlled by German landowners and was considered poor due to their low social status which included hardly any land ownership, the proximity of Riga enabled the Gertrude population to sell any surplus produce in the city's markets, and thus probably to gain access to other resources arriving into the city (Dunsdorfs, 1962).

Most of the cemetery populations included in this study date from the 14th-18th centuries, which was a politically turbulent time for the Baltic region. The modern-day territories of Latvia, Estonia and Lithuania were divided between various political powers, and the borders changed several times following frequent warfare between them. Before the 16th century, Latvia and Estonia were a part of the Teutonic-Livonian Order, while Lithuania was an independent state, the Grand Duchy of Lithuania, with its territory covering modern-day Belarus, and extending into Latvia, Russia and Poland. In 1569, the Grand Duchy became a part of a new state, the Polish-Lithuanian Commonwealth, although it remained largely autonomous (Stone, 2001: 62). The relationship between the Grand Duchy and the Teutonic Order was dominated by frequent warfare (Stone, 2001: 3). After the Livonian war (1558-83), Estonia and a part of Latvia, including the Vidzeme region, were also claimed by the Polish-Lithuanian Commonwealth, while the other part of Latvia became the Duchy of Courland and Semigallia (Šterns, 1998).

The outbreak of the Polish-Swedish war (1600-25) coincided with a year of poor harvests in the Vidzeme region, leading to a widespread famine during the winter of 1601-2. The situation was exacerbated by raids of the Polish army in the region. With no food sources left, hundreds of people from the affected region migrated to Riga for help, where they died in great numbers from exhaustion and cold, despite rations of food and housing, provided by the authorities (Napiersky, 1890). It is believed that most of these people were buried in St Gertrude's cemetery (Actiņš et al., 2009, Pīrangs, 1932, Rusovs, 1926). The presence of two 17th century mass graves in the cemetery might therefore be linked to this historical event.

Following the war, the territory of Estonia and Latvia previously acquired by the Polish-Lithuanian Commonwealth was retaken by Sweden, but another conflict between 1655 and 1660 between Sweden and its adversaries saw the weakening of the Duchy of Courland and Semigallia, which became the territory of Polish-Lithuanian Commonwealth, while the former territory of Livonia, including Vidzeme and Estonia, remained under Swedish rule. The Russian Empire was one of the adversaries, and its army besieged Riga for three months during August-October 1656 (Frost, 2000: 177). Although the political powers changed, the land in the former Livonia and the Duchy of Courland and Semigallia, and the small-scale farmers who worked on it largely remained in the control of German landowners (Dunsdorfs, 1962: 183). A similar system of landowners and subsistence farmers who worked the land was true for the Polish and Lithuanian Commonwealth, although in this case the land was in the hands of the Polish and Lithuanian aristocracy (Baczkowski, 1999: 55-61).

Following the Great Northern War (1701-21), Estonia and Vidzeme, and later the Duchy of Courland and Semigallia (1722), were incorporated into the Russian Empire, although the whole territory remained largely autonomous with regard to land ownership. The territory of the former Polish-Lithuanian Commonwealth was divided on three separate occasions, and at the end of the 18th century Lithuania also became a part of the Russian Empire.

1.2 Markers of physical health included in this study

Palaeopathological and metrical data included in this study were chosen primarily according to their potential for revealing information about the living conditions experienced by the cemetery populations. A brief description of the lesions and the conditions causing them, as well as adult stature, is given below.

Dental caries is caused by organic acids, which form in the fermentation process of dietary carbohydrates by bacteria in plaque, especially sugars (Hillson, 2008: 291, Zero et al., 2008: 338). Accordingly, caries prevalence can be used to detect the presence of carbohydrates in diet, and/or access to refined sugar in the post-medieval period.

Caries-induced infection of the pulp cavity is believed to be one of the most common reasons for the development of periapical lesions (PL) (Hillson, 2008: 322, Sivapathasundharam, 2009: 490), and these can be present when teeth with carious lesions have been lost antemortem. PL can therefore help to interpret the presence of dental decay even when the teeth have been lost ante- or post-mortem. Dental disease, particularly caries and periodontal disease (PD), often leads to teeth being lost before the individual's death, or better termed antemortem tooth loss (AMTL) (Brennan et al., 2017, Ogden, 2008: 288). AMTL was included in the study for its potential to reveal the overall dental health of the cemetery populations because of its many causes (caries, periapical lesions and PD).

Linear enamel hypoplasia (LEH) forms in early childhood and represents a short-term disruption of enamel formation (DDE Index, 1992). Modern clinical studies have reported the presence of hypoplastic defects in response to various conditions affecting child health, such as infections (Fiumara and Lessell, 1970, Pascoe and Seow, 1994, Stagno et al., 1982), metabolic disorders (Andrade et al., 2013, Seow and Latham, 1986, Seow et al., 1990), premature birth (Seow et al., 1987), or nutritional stress (Seow and Perham, 1989, Sweeney et al., 1971). Enamel defects can also be inherited (Witkop, 1988). In most archaeological populations, defects that affect numerous teeth in the same individual are believed to have resulted from episodes of arrested growth in childhood (Goodman, 1991, Goodman and Rose, 1991: 281, King et al., 2005: 547). This is supported by modern studies, including a high prevalence of LEH on the primary dentitions of native Australian children who had experienced a combination of low birthweight, respiratory and gastrointestinal infections, and/or being born into families with a history of deprivation, especially with regard to the mother (Pascoe and Seow, 1994). Accordingly, the prevalence of LEH in an archaeological population might point to the overall health of women and young children and is therefore a useful tool for comparative studies.

Cribra orbitalia, or abnormal porosity of the orbital roof, and similar porous lesions in the skull vault, porotic hyperostosis (PH), have often been linked in clinical and archaeological studies to acquired or genetic anaemia - low concentrations of haemoglobin or red blood cells (Holland and O'Brien, 1997, Lanzkowsky, 1968, Mittler and Van Gerven, 1994, Ortner, 2003: 363-375, Oxenham and Cavill, 2010, Ross and Logan, 1969, Stevens et al., 2013, Stuart-Macadam, 1987a, 1987b, 1992). On the other hand, numerous other conditions, including subperiosteal inflammation in vitamin C and D deficiencies, as well as subperiosteal haematomas, are also thought to result in similar lesions (Ma'luf et al., 2002, Sabet et al., 2001, Wapler et al., 2004, Woo and Kim, 1997). As the condition only forms in childhood (Allen et al., 2004, Halvorsen and Bechensteen, 2002), it was included in this study as a means of comparing evidence for compromised physical health in childhood in cemetery populations.

Adult stature was also included in this study because attained stature can be influenced by nutrition and physical health status during growth. Studies on living populations from developing countries have clearly linked inadequate nutrition and enteric infections in children to stunted growth and reduced adult stature (Alderman et al., 2006, De Onis and Blössner, 2003, Guerrant et al., 2008, Komlos, 1994). Likewise, undernourishment in mothers negatively affects the growth of the child, as well as the attained stature of the child when they become an adult, and birthweight of their offspring (Victora et al., 2010). Studies on living populations have led researchers to use stature estimates in archaeological populations as a proxy for general physical health status (Armelagos and van Gerven, 2003, Floud et al., 2011, Koepke and Baten, 2005, Steckel et al., 2002). In particular, comparative studies of contemporary archaeological populations from varying socioeconomic environments have found a positive correlation between access to protein sources and higher adult stature, and vice versa (Komlos, 1994, 1998). Since data on adult stature is available from other Baltic archaeological populations of various periods, the data are used here as a comparator for living conditions in the post-medieval period.

2. Materials

2.1 St Gertrude Church Cemetery

The 721 individuals excavated from the St Gertrude Church Cemetery in 2006 were the focus of this study. During the excavation, two mass graves were discovered among the single discrete burials in the cemetery, with archaeological dating placing both in the 17th century.

Previous analysis of dental wear and disease studied by context (GC, and each mass grave), revealed some statistically significant differences in prevalence between them, while carbon and nitrogen isotope analysis did not show any detectable dietary differences between the contexts (Petersone-Gordina et al., 2018). Incremental dentine analysis of teeth from 19 children found similar dietary profiles for children buried in both mass graves, while all profiles in the GC were different. Moreover, four out of six children from one of the mass graves showed evidence for nutritional stress shortly before death, suggesting that it might relate to the famine of 1601-2 (Petersone-Gordina et al., Forthcoming (a)). Strontium isotope analysis on the same 19 children, however, showed no statistically significant differences in ratios between the contexts, suggesting that most of the sampled individuals probably had been born and raised in Riga and/or in its vicinity, although a child from one of the mass graves might have come from rural Vidzeme (Petersone-Gordina et al., Forthcoming (b)). Consequently, it is assumed here that people buried in the MGs represent different populations, including Gertrude village, inner Riga, and probably rural Vidzeme, while most people from the GC were likely from Gertrude village. There were 435 people in the GC (118 males, 109 females, 18 adult individuals, and 190 non-adults aged 0-18 years) and 286 in the MGs (109 males, 82 females and 95 non-adults aged 0-18 years). Adult individuals from the GC for whom sex estimation was not possible, were excluded from further study.

A detailed demographic profile, as well as data on dental disease, CO and LEH used in this study have been published previously (Petersone-Gordina et al., 2018, Petersone-Gordina et al., Forthcoming (c)).

2.2 Comparative populations

Data on comparative cemetery populations are summarised in Tables 1 and 2. Most low-moderate status urban and rural populations represent the local, native inhabitants of Latvia, Estonia and Lithuania, who are believed to have had restricted access to resources in most areas. The Riga Dome Square cemetery (RDSC) and Riga St Peter's Church cemetery (RSPCC) populations represent "ordinary" townspeople of Riga, who were most likely of different nationalities and of low-moderate social status. The urban population of Jelgava Holy Trinity Church cemetery (JHTCC) mostly comprised people of German ethnicity, while those buried in Valmiera St Simon's Church cemetery (VSSCC) were people of both of German and Latvian ethnicities, who could afford to pay for burial in this cemetery (Zariņa, 2008). Although these people enjoyed higher social status due to acquired wealth, they were not as wealthy as members of the aristocracy (Pētersone-Gordina and Gerhards, 2011, Pētersone-Gordina et al., 2013, Zariņa, 2008).

Table 1. Comparative cemetery populations used in the study.

Site	Status	U/R	N	Reference	Century AD
LATVIA					
RDCC	a	U	50	Gerhards, 2009b	15^{th} - 16^{th}
RDSC	l/m	U	107	Gerhards, 2009b, Zariņa, 2008	14^{th} - 17^{th}
RSPCC	l/m	U	118	Spirģis, 2012	14^{th}-18^{th}
JHTCC	h	U	108	Pētersone-Gordina and Gerhards, 2011, Pētersone-Gordina et al., 2013	17^{th} - 18^{th}
VSSCC	h	U	164	Zariņa, 2008	14^{th} – 17^{th}
Saldus church	a	U	13	Gerhards, 2000	
Saldus general	l/m	U	16	Gerhards, 2000	16^{th} – 17^{th}
Ventspils	l/m	U	103	Gerhards, 2005b	15^{th} -17^{th}
Madona	l/m	R	85	Gerhards, 2006	16^{th} -17^{th}
Cesvaine	l/m	R	46	Gerhards, 2006	14^{th}-17^{th}
Tērvete	l/m	R	21	Gerhards, 2000	15^{th} -16^{th}
Priedīši	l/m	R	19	Gerhards, 2000	17^{th} – 18^{th}
LITHUANIA					
Lithuanian aristocracy	a	U	71	Palubeckaité and Jankauskas, 2001	15^{th}-18^{th}
Subačius Street (Vilnius)	l/m	U	88	Palubeckaité and Jankauskas, 2001, Palubeckaitė et al., 2002	15^{th}-18^{th}
Old Panevėžys	l/m	U	284	Jatautis and Mitokaitė, 2013	16^{th} – 17^{th}
Rukliai	l/m	R	50	Palubeckaité and Jankauskas, 2001	16^{th}-17^{th}
Alytus	l/m	U	1152	Jankauskas, 1995	14^{th}-17^{th}
ESTONIA					
PSJCC	l/m	U	117	Allmäe and Limbo, 2010, Limbo, 2009	16^{th} -18^{th}
Tääksi	l/m	R	125	Allmäe, 1999, 2000	14^{th}-18^{th}
Kaberla	l/m	R	42	Heapost, 2003, Mark, 1962	15^{th} -17^{th}
St Barbara (Tallinn)	l/m	U	128	Allmäe, 1999, 2000, Heapost, 2003	14^{th} -17^{th}

U, R – urban or rural living environment; a-aristocracy; h - high social status; l/m-low-moderate social status; RDCC-Riga Dome Church cemetery; RDSC-Riga Dome square cemetery; RSPCC-Riga St Peter's Church cemetery; JHTCC-Jelgava Holy Trinity Church cemetery; VSSCC-Valmiera St Simon's Church cemetery; PSJCC-Pärnu St John's Church cemetery

With regard to the urban Pärnu St John's Church cemetery in Estonia (PSJCC), historical data suggest that, from 1617 onwards, it was used exclusively for burials of the Pärnu garrison soldiers and their family members. These people represented a variety of origins, including native Estonian, Swedish and Russian, who were of low-moderate wealth (Allmäe and Limbo, 2010).

People from the highest social stratum, or aristocracy, were buried inside churches in Latvia and Lithuania. In Latvia, most of these people were either clergymen of a high social standing, or very rich landowners, who were mostly of German descent (Caune and Tilko, 1990: 68-70, Zariņa, 2008: 40). There were two aristocratic populations available for consideration from Latvia (Saldus Church, and Riga Dome Church cemetery - RDCC), and four from Lithuania (Table 2). Data on Lithuanian aristocracy have been pooled from four sites by previous researchers (Palubeckaité and Jankauskas, 2001), and are treated similarly in this study.

Table 2. Lithuanian aristocratic populations by cemetery site.

Site	**N**	**Century AD**
Bernardinian church	12	17^{th} – 18^{th}
Franciscan church	28	15^{th} - 16^{th}
Vilnius Cathedral	22	16^{th} – 18^{th}
Videniškiai church	9	18^{th} - 19^{th}
Total	**71**	

Evidence for porotic hyperostosis was not recorded for any of the comparative Estonian and Lithuanian populations, and the condition has not been reported in any of the recently observed Latvian cemetery populations. In addition, none of the populations have been studied for marrow hyperplasia radiographically. Accordingly, cribra orbitalia in this study was treated as an indicator of compromised physical health in childhood, rather than as representing a specific aetiology.

3. Methods

Methods for estimating age at death and sex in the St Gertrude's cemetery population have been published previously (Petersone-Gordina et al., 2018), but a summary of methods is given in Table 3.

In terms of metrical data for stature calculations, measurements of bones of the upper and lower extremities were used from adult individuals where growth was complete, and no pathologies had deformed the bone. The measurements of long bones (humerus, ulna, radius, femur and tibia) from both sides were taken according to Martin and Saller (1957). The stature of adults was reconstructed according to Gerhards (2005a).

To generate larger sample sizes for the comparative study, relevant palaeopathological and stature data from broadly contemporary cemetery populations in the Baltic region were included in these analyses, regardless of the different methods used for recording. Only prevalence data by individuals with observable and/or affected skeletal elements were used for comparisons. Where possible, prevalence rates for males, females and children were compared separately. Where the number of observed individuals was given in the original publication, statistical tests were employed to compare prevalence rates. To compare groups of less than five individuals, Fisher's exact test was employed. To compare five individuals or more, the chi-square test was used. For comparative analysis of stature estimates, unpaired t-tests were used. The significance level for the tests was set at 0.05. Detailed results of statistical analysis can be found in Table S7.10, Supplementary Material S7, while p values are given in the text.

Table 3. A summary of sex and age estimation methods used for the St Gertrude's cemetery population (from Petersone-Gordina et al., 2018).

ADULT SEX ESTIMATION	
Morphological traits of the pelvis and skull	Buikstra and Ubelaker, 1994: 16-38, Milner, 1992, Phenice, 1969
ADULT AGE ESTIMATION	
Degeneration of the pubic symphysis	Brooks and Suchey, 1990, Meindl et al., 1985
Degeneration of the auricular surface	Buckberry and Chamberlain, 2002, Lovejoy et al., 1985
Degeneration of the sternal rib ends	Işcan et al., 1984,1985, Loth and Iscan, 1989
Cranial suture closure	(Meindl and Lovejoy, 1985
NON-ADULT AGE ESTIMATION	
Tooth formation and eruption	AlQahtani et al., 2010
Epiphyseal fusion of the long bones	Ogden et al., 1978, Schaefer, 2008
Long bone length	Fazekas and Kósa, 1978, Maresh, 1970

4. Results

4.1 Comparing age and sex estimation methods

Adult sex, and adult and non-adult age at death in most of the Latvian, Lithuanian and Estonian comparative skeletal populations had been estimated following morphological criteria detailed in Buikstra and Ubelaker (1994: 16-38). In Estonian populations, apart from this methodology, craniometric data were also used for adult individuals (Alekseev and Debets, 1964). In the skeletal population from JHTCC, Latvia, the methods for age and sex estimation, as well as pathological analysis, were identical to those used for the St Gertrude's cemetery population.

4.2 Comparing palaeopathological and stature estimation methods

While only macroscopically observable lytic lesions on the teeth were recorded as dental caries by all researchers, the calculation of prevalence rates differed between the populations. In the JHTCC and St Gertrude's cemetery populations from Latvia, as well as the PSJCC population from Estonia, all individuals with at least one preserved tooth were included in caries prevalence calculations. Likewise, AMTL in these three populations was classed as present for all alveoli with signs of remodelling, without measuring the depth of the tooth socket. In the VSSCC population, caries and AMTL were observed and prevalence calculated only for individuals with premolars and molars, without specifying more detailed "inclusion" criteria (Zariņa 2008: 51). In the populations from Madona, Cesvaine, and Ventspils, caries was considered absent only in individuals with at least eight unaffected molars. AMTL in the Madona, Cesvaine, and Ventspils populations was recorded as present in all alveoli, which had remodelled at least 2mm (in relation to intact alveoli) or remodelled completely. In all the Latvian populations and the PSJCC population from Estonia, the presence of PL was assessed macroscopically, including all individuals with observable mandibular and maxillary alveolar bones. For the Tääksi population, the methods for recording and calculating prevalence for caries and PL were not specified (Allmäe, 1999).
To control for significant differences caused by different methods used to analyse the skeletons from the comparative populations, caries prevalence in the St Gertrude's cemetery population was re-calculated. Where caries was classed as absent only in people with at least eight observable molars (Gerhards, 2005b), the prevalence rates were slightly higher,

but they were not significantly different from the prevalence rates calculated which included all individuals with at least one observable tooth (see tables S7.8 and S7.9, Supplementary Material S7). Including only individuals with at least one molar and/or premolar in the analysis yielded identical results for males from both contexts, while the prevalence of caries in females from the GC and MGs was 2.1% and 1.1% higher, respectively, due to a slight reduction in observable individuals. Due to the insignificant variation, the re-calculated prevalence rates from the St Gertrude’s population were not used in comparative analyses. Re-calculation of AMTL by only including individuals with molars and/or premolars (or their remodelled alveoli) yielded identical results to calculations that included all individuals with at least one tooth/alveolus present.

Methods used for recording LEH differed in all Estonian and Lithuanian cemetery populations. For the St Gertrude’s cemetery population, LEH was recorded on all observable teeth, and all individuals with at least one tooth were included in the analysis. For Old Panevėžys, LEH was only recorded on canine teeth, and only individuals with at least one canine tooth were included in the analysis (Jatautis and Mitokaitė, 2013). For the other Lithuanian cemetery populations, LEH was recorded on all permanent teeth on the left side of the jaw, or their right counterparts where the left were missing, and prevalence was calculated on all individuals with at least one observable tooth (Palubeckaité and Jankauskas, 2001). For the Estonian PSJCC population, LEH was recorded in individuals with at least one central upper incisor, and one lower canine present for observation (Allmäe and Limbo, 2010).

To control for statistically significant differences in prevalence rates caused by different methods, LEH in the St Gertrude’s cemetery population was also calculated using the methods for the Old Panevėžys and PSJCC populations. Including only individuals with at least one observable canine tooth yielded almost identical results to the original method, while including people with at least one upper incisor and one lower canine, reduced the number of observable individuals, and increased prevalence rates (Table S7.8, Supplementary Material S7). The differences between the original and recalculated results, however, were not statistically significant (Table S7.9, Supplementary Material S7). It was therefore assumed that the results were comparable in all populations despite the differences in recording methods. The method used for recording LEH in other Lithuanian populations was similar to that used for the St Gertrude’s cemetery population, and thus was not tested for differences. Only results obtained by the original method described above were used in the comparative analysis.

Methods for recording CO were similar in all comparative populations, whereby all individuals with at least one orbit sufficiently preserved were observed for porosity in the orbital roof, as defined by Stuart-Macadam (1985, 1988, 1989, 1992). Likewise, the number of observed and affected individuals by age (adult and non-adult) and sex group were given for most populations, except Latvian Cesvaine, and Estonian PSJCC and Tääksi, from which only some data were available (Table 4).

For stature estimates, equations provided by Trotter and Gleser (1952) were used for the Estonian and Lithuanian populations. Due to the lack of certain data (number of individuals, and/or standard deviation of the calculations) in Estonian and Lithuanian populations, meaningful inter-population comparisons using statistical significance tests were only possible for Latvian cemetery populations. Likewise, it was noted that estimates using equations by Trotter and Gleser (1952) yielded higher statures in Latvian populations (Gerhards, 2005a). For this reason, stature between the Baltic populations, where different calculation methods have been used, can only be regarded as an approximate guide.

4.3 Results of the comparative analysis

The prevalence of dental disease was comparable for the St Gertrude's cemetery population, six Latvian and two Estonian populations, but there were no data from contemporary Lithuanian populations (Table 4). In men from the GC and two other urban populations of low/moderate status, caries prevalence was above 60%, and did not differ significantly. Comparison between males from the GC and moderate status rural populations revealed little variation, except the lower rates observed in Cesvaine. The difference, however, was not statistically significant (p=0.066). Although in males from high-status JHTCC and VSSCC populations the condition was less prevalent, the difference was not statistically significant (p=0.070).

For men buried in the MGs, caries prevalence rates were largely similar in the rural Tääksi cemetery (55.2% and 61.9%, respectively), while men from Madona had the highest rates at 75.0%, and people from Cesvaine the lowest (28.5%). The differences, however, were not statistically significant between people from the rural groups (p=0.133). Contrasting caries rates in males from the MGs against moderate status urban populations did not reveal significant differences. Likewise, despite lower caries rates in the high-status VSSCC population, the difference with the MGs was not statistically significant (p=0.227).

Table 4. Prevalence of caries, periapical lesions and ante-mortem tooth loss in post-medieval Latvian and Estonian cemetery adult populations.

		Caries n/N	**%**	**PL n/N**	**%**	**AMTL n/N***	**%**
	LATVIA						
SGCC_GC	Males	27/44	**61.4**	18/44	**40.9**	23/44	**52.3**
	Females	16/40	**40.0**	14/40	**35.0**	25/40	**62.5**
SGCC_MGs	Males	45/87	**55.2**	38/88	**43.1**	52/88	**59.1**
	Females	31/54	**57.4**	17/54	**31.5**	33/54	**61.1**
JHTCC	Males	8/20	**40.0**	6/21	**28.5**	13/20	**65.0**
	Females	19/25	**76.0**	11/25	**44.0**	23/27	**85.1**
VSSCC	Males	3/11	**27.3**	No data		8/14	**57.1**
	Females	9/12	**75.0**			4/11	**36.3**
Ventspils	Males	16/25	**64.0**	11/28	**39.3**	16/23	**57.1**
	Females	10/17	**58.8**	10/20	**50.0**	14/20	**70.0**
Madona	Males	6/8	**75.0**	1/7	**14.3**	9/14	**64.2**
	Females	7/9	**77.8**	1/7	**14.3**	7/13	**53.8**
Cesvaine	Males	4/14	**28.5**	5/21	**23.8**	12/23	**52.2**
	Females	4/11	**36.4**	8/19	**42.0**	13/19	**68.1**
	ESTONIA						
PSJCC	Males	15/24	**62.5**	11/25	44.0	11/26	45.8
	Females	13/21	**61.9**	7/21	33.3	15/25	60.0
Tääksi	Males	13/21	**61.9**	10/22	45.5	No data	
	Females	15/21	**62.5**	9/24	37.5		

n - number of individuals with dental disease; N - number of individuals with observable teeth/alveoli; PL-periapical lesions; AMTL - antemortem tooth loss; SGCC-St Gertrude Church cemetery

Women from the GC were the least affected by caries in the moderate status urban group, while people from Ventspils and PSJCC had higher rates. Despite variation, caries prevalence between these populations was not statistically significant (p=0.190). Women from rural Madona and Tääksi were affected 37.8% and 22.5% more frequently than in the GC, respectively; the difference was statistically significant with Tääksi, but not with Madona (p=0.039 and p=0.092, respectively). Women from the high-status VSSCC and JHTCC populations had a high caries prevalence, with over 70% of individuals affected. Prevalence in the GC proved to be significantly lower than in people from the JHTCC (p=0.01), but not the VSSCC (p=0.072).

In women from the MGs and rural populations, the rates differed. While around 60% of females from the MGs and Tääksi had caries, over 75% of individuals were affected in Madona, but less than 40% had the lesions in Cesvaine. These differences, however, were not statistically significant (p=0.175). Contrasting caries prevalence in females from the MGs and moderate status urban populations also did not vary significantly. Likewise, higher caries rates in the high-status VSSCC and HTCCP did not prove to be statistically significant when compared to women from the MGs (p=0.200).

PL largely mimicked caries prevalence rates described above (Table 4). In men, the prevalence was around 40% in the GC and MGs, as well as in other urban and rural populations, except rural Madona and Cesvaine, and the high-status JHTCC, where the prevalence was lower. This difference did not prove to be statistically significant between males from the MGs, GC, and either Madona, Cesvaine or the JHTCC (p=0.246). In women, the prevalence of PL also ranged between 30% and 40% in most observed populations, regardless of social status and living environment. In people from urban Ventspils, the prevalence was higher at 50%, while in females from rural Madona it was lower at 14.3%. The differences, however, were not statistically significant between the GC, MGs, Madona, and Ventspils (p=0.308).

With regard to AMTL, in men the prevalence was above 50% in the St Gertrude's cemetery population and all comparative populations, regardless of social status and living environment, with people from the high status JHTCC affected most frequently (65.0%). In women, prevalence was more varied, with between 60% and 70% of individuals affected in most of the populations, while just over 36% of females were affected in high-status VSSCC, and 85.1% in the high-status JHTCC. Despite the observed differences, they did not prove to be statistically significant between women from the GC, MGs and Valmiera (p=0.268), or the GC, MGs and the JHTCC (p=0.072).

The prevalence of LEH in the St Gertrude's cemetery was comparable with the JHTCC population from Latvia, as well as four cemetery populations from Lithuania, and one from Estonia (Table 5). In all adult populations, LEH ranged in frequency between 67% and 89% of the observed individuals for both males and females. Notably, all the 88 people from the Subačius street population had enamel defects. This was significantly higher than the total adult prevalence in the GC and MGs (p<0.001). With regard to children, LEH prevalence was significantly higher in the MGs than in all three populations for which data were available (all p<0.001), and also significantly higher in children from the GC than the high-status JHTCC (p=0.015), where no children were affected.

Table 5. Prevalence of linear enamel hypoplasia in post-medieval cemetery adult populations from Latvia, Lithuania and Estonia.

<table>
<tr><th></th><th>Males</th><th>%</th><th>Females</th><th>%</th><th>Children</th><th>%</th><th>Total</th><th>%</th></tr>
<tr><td colspan="9">LATVIA</td></tr>
<tr><td>SGCC_GC</td><td>34/44</td><td>77.3</td><td>27/40</td><td>67.5</td><td>28/95</td><td>29.5</td><td>89/179</td><td>49.7</td></tr>
<tr><td>SGCC_MGs</td><td>63/87</td><td>72.4</td><td>42/54</td><td>77.8</td><td>43/66</td><td>65.1</td><td>148/207</td><td>71.5</td></tr>
<tr><td>JHTCC</td><td>17/20</td><td>85.0</td><td>17/19</td><td>89.4</td><td>0/19</td><td>0.0</td><td>34/58</td><td>58.6</td></tr>
<tr><td colspan="9">LITHUANIA</td></tr>
<tr><td>Old Panevėžys*</td><td>46/57</td><td>80.7</td><td>43/57</td><td>75.4</td><td>4/26</td><td>15.4</td><td>93/140</td><td>66.4</td></tr>
<tr><td>Subačius str.</td><td colspan="4" rowspan="3">No data</td><td colspan="2" rowspan="3">Not recorded</td><td>88/88</td><td>100.0</td></tr>
<tr><td>Rukliai</td><td>43/50</td><td>86.0</td></tr>
<tr><td>Lithuanian aristocracy</td><td>62/71</td><td>87.3</td></tr>
<tr><td colspan="9">ESTONIA</td></tr>
<tr><td>PSJCC**</td><td colspan="6">No data</td><td>42/47</td><td>89.4</td></tr>
</table>

*individuals with at least one canine; **individuals with at least one lower canine and one upper central incisor; SGCC-St Gertrude Church cemetery; GC-general cemetery; MGs-mass graves

Prevalence rates of CO showed variation in most observed populations (Table 6). In men from St Gertrude's cemetery they proved to be rather high, compared to other urban and rural Latvian populations, as well as to the Tääksi and Alytus populations. Only men from Ventspils and urban Old Panevėžys also had similarly high CO prevalence. The differences proved to be statistically significant between males from the GC and the urban populations of RDSC (p=0.001) and Alytus (p=0.002), but not the high-status VSSCC and JHTCC (p=0.052 and 0.841, respectively), and rural Madona, and Cesvaine (p=0.138). In men from the MGs, CO prevalence proved to be significantly higher than in men from the urban RDSC (p=0.018), but not Alytus (p=0.056), or rural Madona, and high-status VSSCC (p=0.054).

In most female populations, including the GC and MGs, CO prevalence ranged from over 8% to over 15%, but it was higher in women from rural Madona (25%) and urban Old Panevėžys (38.2%), while no individuals were affected in the high-status VSSCC. The differences were not statistically significant between the GC, MGs, Madona, and VSSCC (p=0.185), but the prevalence of lesions in women from Old Panevėžys proved to be significantly higher than in both the GC and MGs (both p=0.003).

Table 6. Prevalence of cribra orbitalia in post-medieval cemetery populations from Latvia, Lithuania and Estonia.

	Males	%	Females	%	Children	%	Total	%
LATVIA								
SGCC_GC	12/45	**26.7**	3/36	**8.3**	34/85	**40.0**	49/166	**29.5**
SGCC_MGs	15/86	**17.4**	8/62	**12.9**	33/64	**51.6**	56/212	**26.4**
RDSC	9/139	**6.5**	10/95	**10.5**	18/69	**26.1**	37/303	**12.2**
JHTCC	8/36	**11.1**	9/47	**13.6**	3/14	**21.4**	20/97	**20.6**
VSSCC	0/16	**0.0**	0/16	**0.0**	4/14	**28.6**	4/46	**8.7**
Ventspils	6/29	**20.7**	4/26	**15.4**	8/15	**53.3**	18/70	**25.7**
Madona	0/13	**0.0**	3/12	**25.0**	6/12	**50.0**	9/37	**24.3**
Cesvaine	3/26	**11.5**	2/19	**10.5**	No data		5/45	**11.1**
LITHUANIA								
Old Panevėžys	18/63	**28.6**	21/55	**38.2**	19/33	**57.6**	99/146	**67.8**
Alytus	30/319	**9.4**	38/396	**9.6**	88/369	**23.8**	156/1084	**14.4**
ESTONIA								
PSJCC	Adults total			**15.5**	14/28	**50.0**	22/80	**27.5**
Tääksi		**7.1**		**39.1**		**44.1**		**36.3**

SGCC-St Gertrude Church cemetery

In all the children, the prevalence of CO was higher than in adults from the same populations. Over 40% of children were affected in the GC and MGs, as well as the urban Ventspils, Old Panevėžys and PSJCC, and rural Madona and Tääksi populations. The prevalence was below 30% in both high-status populations, as well as children from RDSC and Alytus populations. CO prevalence in children from the GC was not significantly higher than in the JHTCC (p=0.301), but the difference was significant between children from the GC and Alytus (p=0.004). In children from the MGs, the prevalence of orbital lesions proved to be significantly higher than in children from the urban populations of Alytus (p<0.001) and RDSC (p=0.004), but not the high-status JHTCC and VSSCC (p=0.057).

Stature estimates revealed that men were considerably taller than women in all comparative populations (Table 7). Stature for both sexes, however, varied depending on the region of the cemetery and status. The highest statures were observed in men from high status populations, as well as the low-moderate status urban Ventspils and rural Kaberla populations (all above 171cm). On the other hand, men from moderate status, urban Subačius street and Alytus populations had the lowest stature, at around 168cm.

Table 7. Average stature estimates in post-medieval cemetery adult populations from Latvia, Lithuania and Estonia.

Site		Males	N	SD	Females	N	SD
LATVIA							
SGCC	GC	170.24	102	3.06	156.40	98	2.51
	MGs	169.75	96	2.87	156.08	85	3.15
RDCC		171.20	17	2.80	157.58	14	2.64
RDSC		170.58	96	3.03	155.70	67	2.61
RSPCC		170.66	73	3.47	157.15	45	2.63
JHTCC		171.99	27	3.78	157.13	28	2.93
Saldus Church		171.88	9	1.61	157.61	4	2.27
Saldus General		169.14	9	1.86	156.80	7	2.41
Ventspils		171.25	25	3.60	157.43	17	1.92
Tērvete		170.19	13	2.82	157.20	8	2.60
Priedīši		169.06	11	3.32	154.70	8	2.47
LITHUANIA							
Old Panevėžys		169.70	60	No data	158.00	45	No data
Subačius str.		167.70	-		-	-	
Alytus		168.10			156.90		
ESTONIA							
Tääksi		169.44	16	No data	157.60	16	No data
PSJCC		169.60	27		157.20	25	
Kaberla		171.70	20		155.90	4	
St Barbara		169.46	68		157.67	60	

N-number of individuals; SD-standard deviation; all measurements given in cm; SGCC-St Gertrude Church cemetery; range of stature for men: 167.70-171.99cm; for women: 154.70-158.00cm

Stature of men from the GC was similar to that for people from the urban RDSC and RSPCC populations, as well as rural Tērvete, while men from coastal Ventspils were taller, but those from the MGs, as well as from the rural Saldus general and Priedīši populations, were shorter. The difference between men from the GC and any of these four cemeteries did not prove to be statistically significant (p=0.156, p=0.247, p=0.292 and p=0.231, respectively). When compared to high-status groups, the taller stature of males from Saldus church and the RDCC was not significant against men from the GC (p=0.116 and p=0.228, respectively), but men from the JHTCC population were significantly taller (p=0.013). In males from the MGs, stature was similar to the rural Saldus general, Priedīši, and Tääksi populations, as well as the urban Old Panevėžys, PSJCC and St Barbara populations. People from urban Alytus and Subačius street were shorter, but men from all other populations were taller, especially those from urban Ventspils, as well as Estonian Kaberla, and the high-status populations (RDCC, JHTCC and Saldus church) from Latvia. Statistical tests revealed that men from the MGs were significantly shorter than those from Ventspils (p=0.029), JHTCC and Saldus church (p=0.001 and p=0.031, respectively), but not RDCC (p=0.057).

The stature of women differed less than that of men, but women in high-status populations generally were slightly taller than those in moderate status groups. The stature of females from the GC did not significantly differ from most other urban and rural groups of moderate social status. Although people from the Priedīši population were shorter, the difference seen when compared to the GC was not statistically significant (p=0.068). Women from the MGs were only 0.32cm shorter than those buried in the GC, and comparisons with the other populations are therefore similar, as described above for the GC female population. Although the difference was slightly more pronounced, women from Ventspils were not significantly taller (p=0.092), and those from Priedīši were not significantly shorter (p=0.232). Likewise, females from the high-status RDCC, JHTCC and Saldus church populations were not significantly taller than those from the MGs (p=0.095, p=0.123 and p=0.341, respectively).

5. Discussion

5.1 Comparability of methods

Comparisons of data between the skeletal populations included in this study were often made difficult, or even impossible, by different methods used in recording skeletal pathologies, calculating prevalence rates, and presenting data. While methods for sex and age at death estimates were similar, comparing the prevalence of caries, AMTL and LEH required testing for significant differences, and stature estimates could not be statistically compared between the populations of Latvia and the other two Baltic countries because certain data were not presented (for example, standard deviation), or different prevalence calculation methods were used. Calculating the prevalence of caries and LEH varied most of all, revealing not only different “national” practices, but also variation between individual researchers working in the same country.

In this study, re-calculation of prevalence rates for caries, AMTL and LEH in the St Gertrude’s cemetery population did not yield significantly different results between the original rates and rates using any of the other methods, but it is possible that only including individuals with certain types of teeth in the analysis might reduce the number of observable individuals in some populations, especially those with high rates of AMTL, or where teeth have been lost post-mortem. Likewise, data on LEH by sex group was only available for one out of four Lithuanian populations, while the data were not included for the only Estonian population for which LEH prevalence was available.

With regard to CO, while there was an almost complete dataset from Latvian and Lithuanian populations, detailed regional comparisons were made difficult by the lack of data on the number of observed and affected individuals from Estonian cemetery populations. While percentage prevalence rates were given for most groups, these could not be used for statistical significance tests, thus only making total prevalence rates comparable with the St Gertrude’s cemetery population. Since CO prevalence was substantially different between men, women and children from St Gertrude’s cemetery and several other groups, valuable information might have thus been missed. Difficulties were also encountered when comparing stature estimates between the populations from different regions. For example, the lack of vital data, such as the number of individuals studied, as well as the standard deviation of the mean estimates, made statistical significance tests between regional populations impossible. As a result, any regional differences observed can only be interpreted as approximate, and further research is required.

The differences in recording pathological lesions and calculating stature estimates, as well as reporting the obtained data in the populations discussed in this study highlight the complex international debate about standards for recording in bioarchaeology (Larsen, 2015: 2). In the past, several researchers have pointed out the need for standardisation of methodology in order to make the data available in published work usable for future researchers, as well as to enable regional and global population-based comparisons (Ortner, 1991, Roberts and Cox, 2003: 383-403; Roberts and Manchester, 2010: 7, 29). This debate has resulted in creating a set of general standards for data recording, which are currently used by researchers from different parts of the world (Brickley and McKinley, 2004, Buikstra and Ubelaker, 1994, Steckel et al., 2002). Likewise, specific guidelines have been issued for detailed recording of certain pathologies, such as CO (Stuart-Macadam, 1991) and dental disease (Hillson, 2001, 2008, Lukacs, 1989: 267).

However, calculating the prevalence of dental disease, particularly caries, has remained a challenge, due to researchers following different guidelines, or having received varied levels of training, among other factors (Hillson, 1996: 279-80, Steckel et al., 2002: 70, Stodder, 2012, Temple, 2015). Caffell (2004: 268-279) has illustrated the difficulty of comparing caries prevalence in British medieval populations (AD 450-1540), by revealing considerable variation in presenting and calculating the data in skeletal reports. The lack of standardised methodology for recording dental disease observed during the current research is therefore not surprising, given that a systematic approach to bioarchaeological recording is relatively new in all Baltic States, as is a lack of appropriately trained researchers (Jankauskas and Gerhards, 2012: 470-75), and this problem is unlikely to be solved in the near future due to different traditions practised in each country. It is felt, however, that detailing the methods used, as well as including both prevalence calculated by tooth and by individual (Lukacs, 1989, Roberts and Manchester, 2010: 29), does enable meaningful comparative studies, even if individual researchers have to carry out a pilot comparison of the various methods beforehand. Likewise, including information about the tooth types affected, particularly with regard to caries (Larsen et al., 1991, Temple, 2015: 443), as well as data on AMTL by tooth and by individual would help researchers to estimate the overall prevalence of dental diseases possibly leading to tooth loss during life. To enable comparative studies on certain aspects of childhood health, especially if boys and girls were treated differently, including LEH prevalence in adults by sex group, and not just by total affected/observed individuals, would also be necessary.

5.2 Prevalence of pathological conditions and stature estimates in the St Gertrude's cemetery, and other post-medieval Baltic populations

Although this study compares prevalence rates of certain pathological conditions between archaeological populations, it does not expect to obtain direct answers about their physical health and living conditions as living populations. The prevalence of pathological conditions, while a powerful tool for comparing several aspects of physical health, has its drawbacks. Several authors have called for caution when interpreting these kinds of data as direct evidence for the health status of the living population, because the data are derived from people who have died (Boldsen and Milner, 2012, DeWitte and Stojanowski, 2015, Wood et al., 1992). To improve our understanding of mortality and morbidity in the past, recent studies have encouraged incorporation of interdisciplinary research, such as that from human biology and epidemiology, when interpreting prevalence rates of pathological conditions in archaeological skeletons, rather than simply comparing their prevalence rates (DeWitte and Stojanowski, 2015, Klaus, 2014, Reitsema and McIlvaine, 2014, Temple and Goodman, 2014). Moreover, health in general is very difficult to assess in archaeological populations as "health" is a multi-dimensional term, referring to physical, as well as emotional well-being of living individuals. The World Health Organization defines health as "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" (World Health Organization, 1948), which is impossible to measure in archaeological populations (Reitsema and McIlvaine, 2014). Moreover, physical health is a subjective concept in modern communities (Piperata et al., 2014), and the presence of pathological lesions in an individual does not necessarily mean that they were in poor health (Temple and Goodman, 2014).

As early as 1992, Wood et al. pointed out three key issues to be considered when analysing cemetery populations: first, that they change over time (temporal non-stability); second, that people have varied immunity and thus response to potentially life-threatening conditions (selective mortality); and third, that at any given time some people are more likely than others to die from certain conditions due to age, sex, and other factors (heterogeneous frailty). This is especially true for people buried in the MGs in this research, since this group succumbed to a catastrophic mortality event (see below).

Apart from people in mass graves, most populations considered here represent individuals who died over a timespan of three or four hundred years, and it is important to keep in mind that the results of this research offer a very limited insight into the actual living conditions of these once living populations.

The first area to be considered in this comparative analysis was dental disease. The lack of significant differences between men and women from the GC and the MGs, and most other urban and rural groups of low-moderate social status, suggests similar amounts of carious food in their diet, thus supporting the first part of the first hypothesis proposed. This hypothesis was based on historical evidence suggesting that bread and other cereal based products were staple foods in the post-medieval period across the Baltic region (Dumpe, 1999: 122-27, Hueck, 1845, Hupel, 1774-1782, Laidre, 1999, Limbo, 2009, Straumīte, 1906), although the composition of bread (type of grain used, and amount of inclusions of bran, and other plant material) would have differed among people of higher and lower social status (Hueck, 1845, Lentilius, 1924, Oekonomisches Repertorium für Liefland, 1808-1811).The significant differences in caries rates observed between women buried in the GC and the rural Tääksi population might point to some differences in the composition of the diet between the groups.

The significantly higher caries rates in women from the JHTCC compared to those from the GC partly support the second part of the first hypothesis. Previous studies on dental disease in the JHTCC population suggested that the high caries rates observed in women from this group were probably due to the availability of refined sugar for this population, given that the Duchy of Courland and Semigallia was involved in the trade of colonial goods, especially sugar, which were made available to people of higher social status (Pētersone-Gordina and Gerhards, 2011). On the other hand, comparatively lower caries rates in men from the high-status populations might be explained by a different diet, especially with regard to amount of refined sugar, and/or foods which are known to prevent dental decay, such as milk, cheese and seafood (Hillson, 1996: 279, Zero et al., 2008: 334-5).

The fact that periapical lesions in the observed populations mimicked caries rates, suggests that most lesions had indeed originated as an infection of the pulp cavity due to caries, as explained above (Sivapathasundharam, 2009: 490). Likewise, the high rates of AMTL point to poor oral health in all observed populations. To explore diet and oral health in the Baltic cemetery populations in more detail, particularly in terms of differential coarseness of diet in groups of higher and lower social status, it would be necessary to carry out analysis of dental wear, and conduct isotope analysis.

The high prevalence of LEH in all observed adult populations is suggestive of a high frequency of arrested growth episodes, such as periods of inadequate nutrition or illness for young women and children, but it also strongly points to the likelihood that most people were able to survive them. Indeed, the presence of pathological lesions in a skeleton might indicate that the person was strong enough to survive the episodes causing the lesions, as opposed to a frailer individual who died before developing any response in the skeleton (Wood et al., 1992). Considering this phenomenon, the low prevalence of LEH in children from most of the comparative populations suggests that many children could not survive the same, or similar, episodes of arrested growth and died before developing the lesions. The unusually high LEH prevalence in children from the MGs has been discussed in a previous publication with regard to heterogeneous frailty (Petersone-Gordina et al. Forthcoming (c)). Previously acquired data showed that there were significantly more children with both CO and LEH buried in the MGs, compared to the GC. This was interpreted as probably indicative of higher frailty, whereby children with more than one previous episode of compromised physical health were more likely to die during an epidemic or famine (Petersone-Gordina et al., Forthcoming (c)). A similar trend was observed in the victims of the 14th century Black Death who were buried in the East Smithfield cemetery in London (DeWitte, 2009, DeWitte and Hughes-Morey, 2012, DeWitte and Wood, 2008). Consequently, the high prevalence of LEH in this group cannot be considered as representative for the whole population.

So far, given the lack of statistically significant differences between adults in the St Gertrude's cemetery population and most of the comparative populations, and the frailty of children buried in the MGs, the second hypothesis proposed is not supported. Although the prevalence of LEH was significantly higher in children from the GC than from the JHTCC, this cannot be classed as a pattern, and a wider comparative study that includes more cemetery populations would be necessary.

With regard to CO, the highest prevalence was found in people from urban groups, including the GC, rather than poor rural populations, and there were no statistically significant differences between low-moderate and high-status groups, thus rejecting the second hypothesis. The lack of specific prevalence patterns between urban, rural and high-status groups indicates a differential pathogen load in each community, and even within one city, as was observed in groups from Riga. This suggests that CO prevalence was influenced by local conditions in each community, although it seems that some urban communities were more predisposed than others. Moreover, the observed variation might also be due to several conditions that can cause orbital lesions, as discussed in Section 1.2 above. A better differential diagnosis could be achieved in future studies by recording PH in the skull vault, as well as employing radiographic analysis.

On the other hand, the more pronounced variation in CO prevalence rates between male populations, compared to women, might suggest that the occurrence of CO in females was not influenced by extrinsic factors to the same extent as in males. Previous studies have found that environmental factors influence the stature of boys more than that of girls, due to a weaker immune response to adverse environmental factors (see below). Some clinical studies suggest that the immune response to various diseases also differs according to sex. For example, women generally have more pronounced immune responses to infection than men, although this varies with age (Klein and Flanagan, 2016, vom Steeg and Klein, 2016). Consequently, it is possible that the same pathogen load would have affected boys and girls differently, even if their treatment in terms of access to resources was similar. However, the higher prevalence of CO in children in all observed populations suggests a degree of heterogeneous frailty, essentially that children who had developed the lesions as a response to a pathological condition were more likely to succumb to further episodes of compromised physical health and die in childhood than those who had not. In order to understand if CO prevalence in boys and girls could be influenced by differential immune responses to pathogens, sex estimation of affected children using ancient DNA analysis would be necessary.

Finally, comparison of stature estimates showed that in general, people were taller in higher status groups and shorter in lower status groups, thus partly supporting the third hypothesis, although the differences were only significant in males. Taller statures in people from Riga suggest that they could exploit the opportunities arising from the city being a major trade centre and have access to better resources than people living in rural areas, or in most other cities in the region. Although the differences in stature were not statistically significant between men from the GC and MGs, they resulted in men from the MGs being significantly shorter than those in three out of four high-status populations, unlike males from the GC.

The slightly shorter stature of men from MGs, compared to the GC, might signal a period of compromised access to resources for the generation buried in MGs. Alternatively, it is possible that this group of men had experienced growth failure in early childhood, probably resulting from reduced access to resources and/or episodes of compromised physical health (Stein et al., 2010, Victora et al., 2010); this, in turn, increased their frailty during mass mortality events, a pattern also observed in the victims of the Black Death from London (DeWitte and Hughes-Morey, 2012). With regard to evidence for episodes of compromised childhood health, however, no statistically significant differences were found in prevalence rates for cribra orbitalia and linear enamel hypoplasia between the two groups (Petersone-Gordina et al., Forthcoming (c)).

Shorter stature of women when compared to men in all observed populations is similar to other archaeological studies considering stature, as well as data from modern studies from countries with low-moderate incomes (Addo et al., 2013, Gerhards, 2005a, Koepke and Baten, 2005, Roberts and Cox, 2007). Previous studies on animals, as well as humans, have suggested that women are generally more robust than males in terms of immune response (Grossman, 1985: 257, Ortner, 1998, Talal, 1992), which would also result in less variation in stature, while the stature of boys is more responsive to environmental changes (Eveleth and Tanner, 1990, Kuh et al., 1991). This pattern was also observed in a recent study on 19th century Danish populations (Jørkov, 2015). The lack of statistically significant differences in stature between any female populations in this research seem to support these findings, whereby the stature of women was less variable in response to environmental factors. On the other hand, temporal studies on stature changes in different periods and/or major transition periods have found that female stature can vary as much as that of males over time (Koepke and Baten, 2005, Nicholas and Oxley, 1993).

6. Conclusions

The results of this comparative study only partly supported the hypotheses set out in the Introduction. Firstly, caries rates in high-status women from the JHTCC proved to be significantly higher than in those from the GC, but prevalence in men was more uniform. This was explained by differential diet in the groups, especially with regard to the availability of refined sugar for the JHTCC population, and its differential use by men and women. Secondly, LEH proved to affect most of the observable adults in all groups, pointing to the presence of arrested growth episodes regardless of social status, but also suggesting that most individuals were able to survive into adulthood. Differences in prevalence were most pronounced between children from the MGs and the other groups, probably due to higher frailty, since these children represent a specific group of non-survivors.

Orbital lesions affected children more than adults, thus suggesting that children probably became more vulnerable to further episodes compromising their physical health after developing CO. The considerable variation in CO frequencies between different groups might be partly due to the variety of conditions that can cause the lesions. Finally, stature estimates proved to be higher in high-status groups, although significant differences were only found between males. It therefore seems likely that social status was an important factor for attaining “normal” adult stature, at least for men. The lack of such differences in women might have been due to a less pronounced immune response to environmental conditions, compared to men.

This study has met its main aim and put the St Gertrude’s cemetery population in a regional context, highlighting differences between people from the GC and MGs and other contemporary urban and rural groups. The lack of some data, while preventing a complete comparative study, has raised awareness of the importance of standardising data presentation between researchers from the Baltic States. Including certain information in future publications would enable better cross-comparisons between different populations by future researchers, thus significantly improving the credibility of such studies and helping to generate datasets for more detailed temporal studies in the region.

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Chapter 9. Discussion and Conclusions

The wide variety of data generated during this research has helped to answer the research questions outlined and provided a detailed insight into life and death in post-medieval Riga, and St Gertrude's cemetery in particular (Table 5). This chapter will outline how Chapters 4-8 have answered the research questions and addressed hypotheses, and how the aims and objectives of this project have been met through the different analyses employed. The Discussion is divided into three main sections. Section 9.1 considers the demographic profile of the population; Section 9.2 deals with evidence for different population groups in St Gertrude's cemetery, thus answering Research Question 4, while Section 9.3 considers evidence for several aspects of physical health of the population, and how it compares with other post-medieval populations from Latvia, Lithuania and Estonia, and answers Research Questions 1, 2 and 3; questions 1-4 are outlined in the Introduction and summarised in Table 9.1.

Table 5. Summary of the proposed and achieved aims and objectives and research questions.

AIMS	Aim achieved?	Relevant Chapters
To analyse the remains of 721 individuals excavated from the St Gertrude's cemetery for evidence of dental disease, infectious diseases, and metabolic stress (enamel hypoplasia, cribra orbitalia and vitamin C and D deficiencies), in addition to their biological sex, age at death, and stature	Yes	Chapters 4, 7, 8
To carry out radiocarbon dating from three selected individuals in the mass graves (MGs)	Yes; samples analysed from three individuals from the MGs, and one from the GC	To be published; Appendix 1
To carry out stable nitrogen and carbon isotope analyses on 30 individuals from the MGs (15 from each) and 30 from the General cemetery (GC) for dietary analysis	Yes; sample size increased to 96 individuals in total	Chapter 4
To carry out strontium isotope analysis on eight individuals from the MGs (four from each) and four from the GC for migration analysis	Yes; sample size increased to 19 individuals in total	Chapter 6
To compare the frequencies of pathological conditions between the individuals buried in the GC and the MGs, and to contrast these variables with other broadly contemporary urban and rural cemetery populations from Latvia	Yes	Chapters 7 and 8
To compare the statures and rates of pathological conditions from the cemeteries in Latvia to urban and rural cemetery populations in Lithuania and Estonia	Yes	Chapter 8

To evaluate whether certain patterns emerge in the frequencies of pathological lesions in population groups living in different regions (Latvia, Lithuania and Estonia), living environments (urban and rural), and of differing social statuses	Yes	Chapter 8
To study historical evidence relating to socio-cultural, economic and political factors which might have influenced physical health of populations in the Baltic region in the 15th - 17th centuries.	Yes	Chapter 2
OBJECTIVES	**Objective achieved?**	**Relevant Chapters**
Using the results of the palaeopathological, isotopic and inter-cemetery analysis between the Latvian populations, to determine if the people buried in the MGs could have been rural immigrants	Yes	Chapters 4-7
To obtain radiocarbon dates for the MGs in order to place them in a historical context and to aid the interpretation	Yes; four samples analysed	To be published; Appendix 1
To understand how the political, cultural, economic and social environment influenced certain aspects of physical health of different population groups in the Baltic region during the 15th - 17th centuries.	Yes	Chapters 2, 4-8
RESEARCH QUESTIONS		**Answers**
1. Are the frequent wars, famines and epidemics mentioned in historical sources reflected in the data on physical health and diet, and attained adult stature of the moderately wealthy St Gertrude's cemetery population?		Chapters 7, 8
2. How does the St Gertrude's cemetery population data compare to that from other contemporary urban and rural cemeteries in the Baltic region?		Chapter 8
3. Were urban post-medieval populations in the Baltic region less affected by physical health problems, as reflected in their skeletal remains, than rural populations?		Chapter 8
4. Do the individuals in the mass graves and the general cemetery represent different populations, based on evidence for physical health, diet, stature and strontium isotope ratios?		Chapters 4-7
ADDITIONAL ANALYSIS		
Carbon and nitrogen incremental dentine analysis was carried out on the teeth from 19 non-adult individuals, to observe short-term changes in diet and differences in childhood diet between individuals from different burial contexts, and to identify potential victims of famine in mass graves		Chapter 5

The results of radiocarbon dating carried out on three individuals as a part of this research (one from the general cemetery, and one from each mass grave), have not been included in the five publications (Chapters 4-8). They have provided absolute dates for the mass graves, placing them firmly in the 17th century, although not necessarily in the same year, as well as helped establish that the first burials in the St Gertrude's cemetery occurred in the 14th century (by dating an individual from the lower layer of burials). The results of radiocarbon analysis will be submitted for publication shortly as a separate paper and can currently be found in Appendix 1.

9.1 Demographic profile of the population

The demographic composition of the population sufficiently represents all age and sex groups expected in a typical post-medieval cemetery, particularly in the GC, suggesting that the recovered human remains likely represent a proportionate sample of St Gertrude's cemetery population, even though an unknown area of the cemetery has not been excavated. This reduces the bias of underrepresentation of particular age and/or sex groups often affecting palaeodemographic studies, in this population (Chamberlain 2009: 89).

The reconstructed demographic profile for the population revealed some differences in the presence of specific age groups between the mass graves (MGs) and the general cemetery (GC), especially with regard to the children (Figure 13). The profile of the GC exhibited characteristics of attritional mortality, with a high proportion of children aged between one and 5.9 years (36.6%), but few individuals aged between 12 and 17 years (14.7%). The high number of young children in archaeological populations has been explained by a high risk of mortality in this age group in the past due to infections; the risk of death from infection in early childhood is still considerable in developing countries, with the most common risk factors including overcrowded living spaces, indoor and outdoor pollution, poor sanitation, and limited access to medical care (World Health Organization, 2002b). Many of these conditions would have been encountered by post-medieval populations, as discussed in more detail in Section 9.3 below.

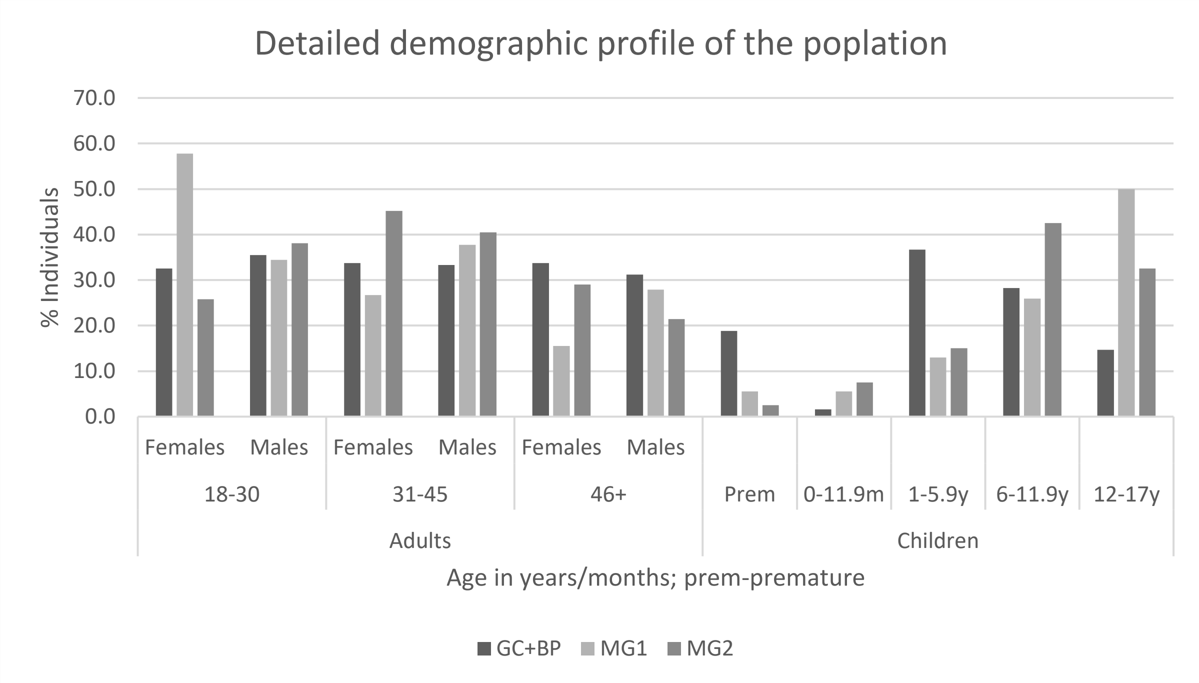

Figure 13. Detailed demographic profile of the St Gertrude's cemetery population.

In both mass graves (MG1 and MG2), while there were fewer young children than in the GC (13% and 15% in MG1 and MG2, respectively), the number of older children was considerably higher (50% and 32.5% in MG1 and MG2, respectively). This points towards catastrophic mortality, whereby older children experienced a high risk of mortality, compared to attritional mortality, whereby younger children are more frequently affected, as discussed in Chapter 2 (Keckler, 1997). On the other hand, the differences in adult age groups were less pronounced, and this might be explained by the fact that many of the deceased in the mass graves represent various population groups, rather than just the local population of St Gertrude village, as discussed in Section 9.2 below, thus skewing the cemetery population.

The lack of young children in mass graves is intriguing; before the results of this research, it was hypothesised that if most people buried in mass graves had come from rural Vidzeme, then it is likely that only children who were able to make the journey together with their parents on foot, would be present in the mass graves. This hypothesis has been largely rejected by this research, and strontium isotope analysis in particular (see Section 9.2 below). Instead, the lack of very young children in mass graves might have a different explanation, including a burial in another location within the cemetery, considering that it has not been completely excavated, or, if the people in mass graves came from various locations around Riga, then the small children from these populations could have been buried in different, local, cemeteries. Poor survival of the remains of very young children is unlikely, as the skeletal remains of children born prematurely, as well as those who died soon after birth, and were recovered from the mass graves, were very well preserved.

9.2 Origin of the populations buried in St Gertrude’s general cemetery and mass graves

9.2.1 Evidence from dental disease and dietary isotope values

The origin of the people buried in St Gertrude’s cemetery, which was consistent with research question 4, was considered in Chapters 4, 5 and 6. In Chapter 4, dental attrition scores, the prevalence of caries, periapical lesions, periodontal disease, calculus, and antemortem tooth loss in adults and children, as well as carbon and nitrogen isotope values in adults, were compared between the GC and the MGs. With regard to dental attrition, several significant differences emerged between adults and children buried in the three contexts. Women did not show substantial differences in dental wear, but it was significantly higher in men from both mass graves than men from the GC, and in children from MG1 than from both other contexts. Likewise, men from both mass graves also had significantly higher attrition rates than women, while the difference between the sex groups was not pronounced in the GC.

This was explained by differential coarseness of dietary staples, particularly bread (Dumpe, 1999); for example, milling bread flour using a hand mill, and adding inclusions of bran and straw into the bread, has been described as a common practice of subsistence farmers in some regions of Latvia, as opposed to the “cleaner”, finer bread of the upper classes, which was milled in larger wind or water-powered mills (Hueck, 1845, Lentilius, 1924). In years of poor harvest, other plant material was included in bread to make the flour last longer, thus further increasing the coarseness of bread (Dumpe, 1999, Oekonomisches Repertorium für Liefland, 1808-1811, Repository of Ethnographic Material of the Institute of Latvian History, University of Latvia). The different practices would have likely resulted in differential dental attrition scores for the people routinely using the product. Alternatively, a higher proportion of other cooked carbohydrates, such as porridge, would result in lower attrition scores (Hueck, 1845, Hupel, 1774-1782, Straumīte, 1906). An example of both a hand mill and a windmill from the period in question is shown in Figure 14.

Figure 14. A hand mill (left) and a wind mill (right) in the Latvian Ethnographic open-air museum, Riga, Latvia.

The lack of statistically significant differences in prevalence rates of caries, periapical lesions and periodontal disease between any population groups, was suggestive of similar amounts of carbohydrates in the diet of all people buried in St Gertrude's cemetery. This is because dietary carbohydrates are thought to be mainly responsible for changes in plaque bacteria, which eventually lead to development of caries (Adler et al., 2013, Hillson, 2005: 291, Larsen et al., 1991: 179, Selwitz et al., 2007, Zero et al., 2008: 338) and periodontal disease (Axelsson et al., 2004, Marsh et al., 2009: 117). Since bread and/or porridge are known to have been the basis of local farmers' diet in the whole territory of Latvia, the lack of significant differences in dental disease between the groups is not surprising. Moreover, this also suggested that neither of the groups consumed a higher proportion of products which are known to prevent caries, such as milk, cheese, and seafood, also supported by the results of isotope analysis (see below), or products which exacerbate the development of caries, such as refined sugar. For example, caries prevalence proved to be low in native populations of Greenland, whose diet was mainly based on marine protein (including sea mammals, seabirds, and fish), as opposed to a considerably higher prevalence of lesions in people from the same populations who were increasingly incorporating newly available imports of grain and sugar into their meals (Møller et al., 1972). Likewise, in women from the high-status German population of Jelgava, who had access to refined sugar, caries prevalence exceeded 70%, compared to below 60% in all female groups in the St Gertrude's population. The differences between these two populations are discussed in more detail in Section 9.3.2.

With regard to periapical lesions, the prevalence was not consistent with caries, although no statistically significant differences were observed between the groups. The lesions in most people were likely related to advanced caries, which had exposed the dental pulp and caused an infection (Hillson, 1996: 284, 2008: 322, Sivapathasundharam, 2009: 490). In men from MG2, who had the highest prevalence of periapical lesions, the high attrition scores might have been an additional factor in their development (Hillson, 2008: 322) (Figure 15).

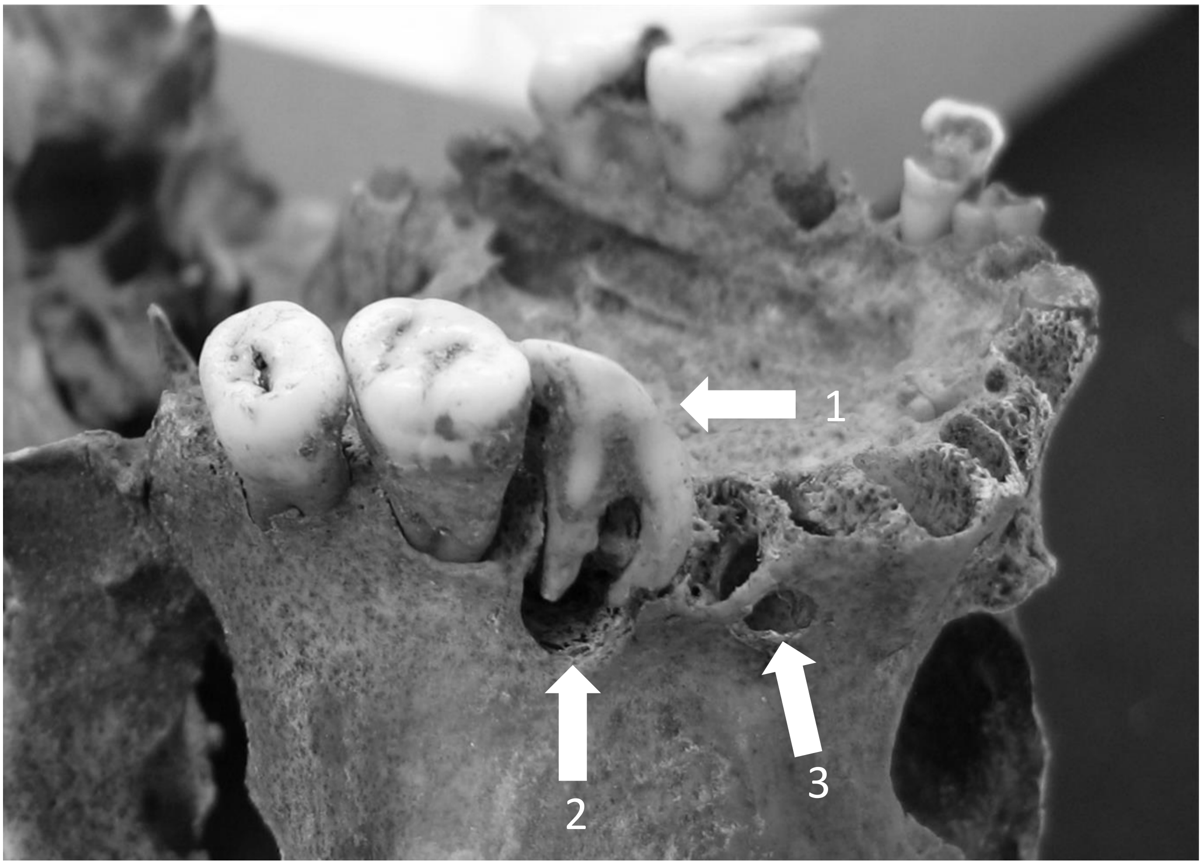

Figure 15. Severe attrition of the left upper M1 (1) and periapical lesions related to the same tooth (2), as well as both premolars (3), in a 30-40 years old male from MG2 (burial 469).

As discussed above, periodontal disease also did not reveal any evidence for dietary differences between people buried in the St Gertrude's cemetery. It was noted, however, that in this population, and particularly in men from MG2, periodontal disease was not linked to low attrition rates (Figure 16). As detailed in Chapters 2 and 4, periodontal disease tends to affect populations who have softer diets (Huynh et al., 2016). The results suggested that instead the condition was likely caused by carbohydrates, and subsequent changes in the bacterial composition of dental plaque in the whole population, rather than differences in the coarseness of their diet (Axelsson et al., 2004, Marsh et al., 2009: 117). The disease might also have been exacerbated by emotional stress, which in known to be the case in modern populations (Genco et al., 1998, Hugoson et al., 2002). Finally, it was concluded that in the light of the high prevalence of destructive dental diseases, particularly caries and periodontal disease, over 50% of AMTL prevalence in all groups was not surprising.

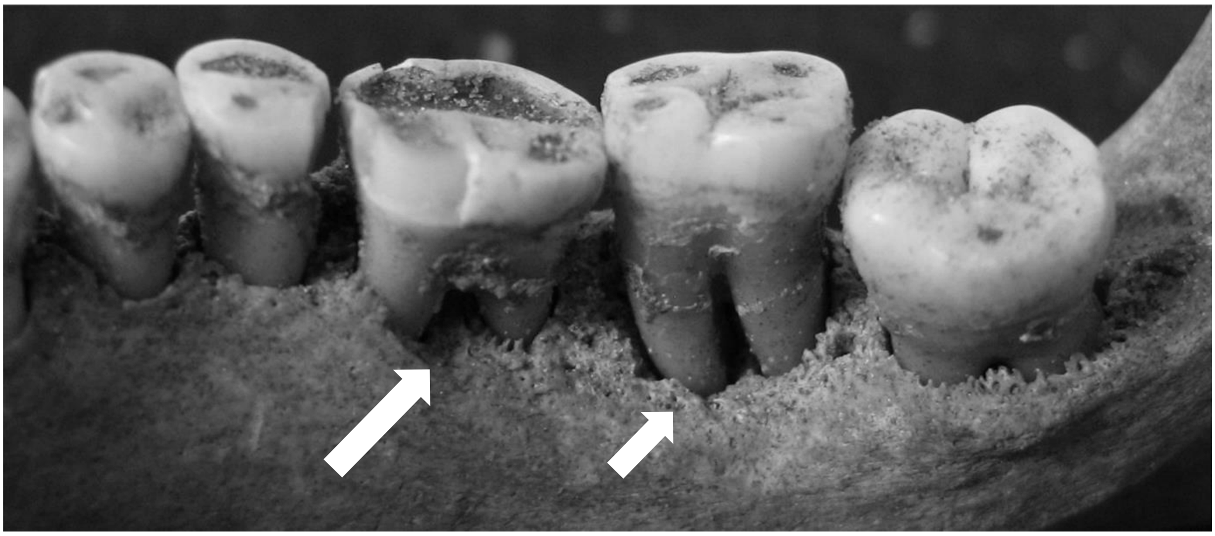

Figure 16. Moderate attrition of M1, with advanced periodontal disease affecting lower right M1 and M2 in a male from MG2, aged 25-30 years (burial 506).

Unlike destructive dental lesions discussed above, the severity of calculus deposits did show some inter-contextual variation, especially in children. Notably, men and women from MG2 had a significantly higher prevalence of medium-heavy deposits than other adult groups, while children from this context, and MG1, were affected by the presence of calculus lesions significantly more frequently than children from the GC. It was suggested that the observed differences might point to variations in the amount and/or composition of dietary carbohydrates used by these groups, given the link between plaque formation, and carbohydrates and sugars in the diet of modern populations (Huynh et al., 2016). To further investigate this possibility, chemical analysis of calculus deposits would be necessary in all populations groups from the St Gertrude’s cemetery. On the other hand, factors other than diet, such as the composition of saliva, also influence the amount of plaque which forms on teeth (Marsh et al., 2009: 96). Likewise, the observed differences might have occurred due to differential survival of calculus deposits in the burial environment (Freeth, 2000).

Overall, the analysis of dental disease revealed differences in the coarseness of diet between the groups, as expressed in differential dental wear, and suggested possible differences in the composition of dietary carbohydrates, based on the prevalence and severity of calculus deposits. The lack of significant differences in the prevalence of caries, periapical lesions, periodontal disease and antemortem tooth loss was taken as evidence for a similar amount of carbohydrates in the diet of the whole population, which was consistent with historical evidence for bread being a staple food of Latvian subsistence farmer populations, as discussed above. While the observed differences were suggestive of the presence of more than one population group in the St Gertrude's cemetery, it was not enough to identify the presence of rural immigrants. This was mainly due to the lack of patterns in the prevalence of destructive dental lesions in other contemporary rural and urban cemetery populations from Latvia, as shown by a previous study, and explained by the complex political situation, as well as regional differences in the availability of resources, general quality of life, and other factors (Pētersone-Gordina and Gerhards, 2011). Likewise, rates of caries and periapical lesions in two cemetery populations from Estonia, one urban and one rural, were very similar to those recorded in the people from St Gertrude's cemetery (Allmäe, 1999, Limbo, 2009). More detailed regional comparisons are discussed in Section 9.3.2 below.

With regard to isotope analysis, the first step, which compared the high-status German population of Jelgava, and the people from St Gertrude's cemetery, revealed obvious differences, with $\delta^{15}N$ values in all individuals from the Jelgava population exceeding 13‰, while the values of all but one individual from St Gertrude's cemetery were below 13‰. The comparative analysis was carried out in order to test if noticeable differences in dietary isotope values would emerge between two distinctive cemetery population groups, before applying a similar analysis to the putative different population groups from St Gertrude's cemetery. The results suggested that the Jelgava population incorporated considerably more freshwater fish in their diet, compared to St Gertrude's cemetery population (Katzenberg, 1989, 2008: 426). This was explained by the fact that the city of Jelgava is situated inland, on the banks of the large river Lielupe, with potentially less access to fresh marine protein, compared to Riga. Likewise, the Jelgava population was of a higher social status, and their dietary choices may well have been different to that of the native Latvian population buried in the St Gertrude's cemetery.

In people from St Gertrude's cemetery, $\delta^{13}C$ values ranged between -21.2‰ and -18.9‰, and the $\delta^{15}N$ values between 8.7‰ and 13.7‰. This suggested a diet dominated by terrestrial resources, with some marine input (McGovern-Wilson and Quinn, 1996, Richards and Hedges, 1999, Schoeninger, 1989, Spielmann et al., 1990, Tauber, 1986), and probably some amount of animal protein in people's diets (Ambrose et al., 2003, O'Connell and Hedges, 1999). Isotopic evidence for a diet mainly based on carbohydrates supported the relatively high prevalence of destructive dental conditions discussed above, and suggested that the amount of certain terrestrial and marine proteins which are known to help prevent dental decay was too small to have any effect on dental health of this population (Zero et al., 2008: 334-5). The positive correlation between $\delta^{13}C$ and $\delta^{15}N$ values suggested that they were determined by the amount of marine protein, rather than different terrestrial $\delta^{13}C$ sources. The lack of any obvious pattern, or meaningful differences in values, between any of the observed groups, pointed to high individual dietary variation, particularly with regard to the presence and amount of marine resources. While the results of the isotope analysis were suggestive of the presence of the same population group in all three contexts of the St Gertrude's cemetery, it was also pointed out that if there were people from rural Vidzeme buried in mass graves, they might be isotopically indistinguishable from the population of Riga. This is because Vidzeme has a long coastline, and there is strong evidence that salted fish, which was relatively cheap and thus available to native populations, was widely sold in Riga and transported to rural inland markets across the whole region; likewise, as already discussed above with regard to dental disease, bread was a staple product for the native Latvian population. Accordingly, the basic composition of the diet might have been largely similar for most urban and rural populations of a similar social status, and this could make them isotopically indistinguishable. Due to the lack of isotope data from other contemporary urban and rural populations of a similar social status, a more detailed comparative analysis was not possible.

Together, the results of dental disease and adult dietary isotope analyses in this population were interpreted as inconclusive with regard to the possible presence of more than one population group in the cemetery. Even though significant differences were observed in dental attrition rates, as well as the presence and severity of dental calculus deposits, the prevalence of dental disease and the isotope data did not yield evidence for substantial inter-contextual dietary differences. The research moved on to the next aspect, incremental dentine analysis, in order to explore dietary differences between individuals buried in different contexts, in more detail.

9.2.2 Evidence from incremental dentine analysis

Incremental dentine analysis of 19 children from St Gertrude's cemetery, discussed in detail in Chapter 5, revealed several dietary aspects, and offered further evidence for the origin of the population groups buried in the cemetery. Firstly, comparative analysis of the mean $\delta^{13}C$ and $\delta^{15}N$ values of non-adult dentine and adult bone, discussed above, suggested that there were no meaningful differences in adult and non-adult diet in any context, and that both groups relied mainly on terrestrial resources, with some marine input for most individuals. Individual values, however, showed considerable variation between incremental dentine profiles, providing detailed information on dietary changes from early childhood to death of each individual.

Secondly, it was noted that while the profiles of children from the GC showed only subtle changes in values, except in individual GC_41, they were more pronounced in most children from the mass graves. It was also noted that several children from both mass graves had similar $\delta^{13}C$ profile patterns, suggesting that they might have come from the same communities. Conversely, dietary profiles of children from the GC showed no similarities in patterns either within the same context, or with children from the mass graves. This was taken as evidence for the presence of people from the same communities in both mass graves, who possibly had a different origin than people buried in the GC.

Thirdly, four out of six children from the MG1 showed evidence for nutritional stress towards the end of their lives, whereby the rise in $\delta^{15}N$ values exceeded analytical uncertainty, without corresponding changes in $\delta^{13}C$ values (Beaumont et al., 2013). This pattern was also observed in children from populations which are known to have experienced famine, or periods of nutritional stress (Beaumont and Montgomery, 2016, Beaumont et al., 2015, Montgomery et al., 2013). Accordingly, this pattern suggested that the children had simultaneously experienced nutritional stress shortly before their death, and thus could be victims of the famine of 1601-2. The lack of evidence for nutritional stress in the remaining two children from this context was explained by the fact that nutritional stress might not be isotopically detectable in people who received adequate nutrition from the authorities of Riga, but who were killed by diseases associated with overcrowded environment and poor sanitation, which would have been part of the living conditions for the refugees (Dirks et al., 1980, World Health Organization, 2002a).

Although the profiles of some individuals from both mass graves showed similar patterns, no evidence for nutritional stress towards the end of life was observed in children from MG2. This suggested that these children had died from an epidemic and, accordingly, that both mass graves might not have been contemporary. Indeed, as pointed out in Chapter 2, the famine coincided with a plague epidemic in 1601, and another plague epidemic broke out just 22 years later, in 1623. It was also pointed out that according to historical sources, people from rural regions came to Riga not only during the famine of 1601-2, but also during other mass mortality events, in the hope of being buried (Napiersky, 1890). This might explain the presence of the people from the same community in both mass graves, even if they were not representative of the same mass mortality event.

Finally, it was observed that most children from all contexts, whose sampled teeth had begun forming before the age of 1 year, showed higher initial $\delta^{15}N$ values compared to the rest of their profile; in seven individuals, the first values exceeded the adult mean, and the subsequent drop in values was not mirrored by similar changes in the $\delta^{13}C$ profile. According to recent research, this was taken as evidence for possible in-utero stress (Beaumont et al., 2015, Kinaston et al., 2009, Nitsch et al., 2011, Richards et al., 2002). In the other three children, where both profiles showed decreasing values at the beginning of life, this was interpreted as possible evidence for weaning (Fuller et al., 2006, Katzenberg et al., 1993, Richards et al., 2002, Wright and Schwarcz, 1999). In the rest of children, the slight decrease in $\delta^{15}N$ values was explained by various factors, including those discussed above, as well as growth and development (Fuller et al., 2004, Gannes et al., 1997, Hobson et al., 1993, Hobson and Clark, 1992, Kalhan, 2000, Katzenberg and Lovell, 1999, Mekota et al., 2006). Although this evidence does not add to the argument about the origin of these children, it nevertheless adds valuable information about nutrition and living conditions in early childhood in the St Gertrude's population, which will be discussed in more detail in Section 9.3 below.

Despite the similarities observed between dietary profiles of children from the mass graves, compared to the GC, it was not possible to confirm that any of these individuals were rural immigrants from Vidzeme. This was because no comparative data from the region was available. Furthermore, it was also indicated that children from the mass graves likely represented the same generation, which had simultaneously experienced numerous hardships, as expressed in their dietary profiles, while people from the GC represented several generations, having died centuries apart. The observed individual variation in people from the GC could therefore be the result of temporal dietary changes, as dictated by changing dietary attitudes, availability of resources, and other factors. Consequently, it was concluded that there remained a possibility that most people buried in the St Gertrude's cemetery represent the same local community. It was suggested that strontium analysis, the next step in the research, would be more conclusive with regard to the origin of the people buried in the cemetery.

9.2.3 Evidence from strontium isotope analysis

Chapter 6 was the last study exploring the origin of people buried in the St Gertrude's cemetery, and dealt with strontium isotope analysis of the teeth of the 19 children for whom incremental dentine analysis had been carried out. A similar analysis had never been carried out in Latvia, and it was not known if strontium ratios from different regions of Latvia would show meaningful differences, considering the relatively uniform underlying geology, which is the basis for this analysis (Gilucis and Segliņš, 2003, Graustein, 1989, Hurst and Davis, 1981, Kawasaki et al., 2002).

The results, however, suggested that there were regional differences in $^{87}Sr/^{86}Sr$ ratios in Latvia, at least between the sampled sites in rural Vidzeme and Riga. It was observed that while most children's enamel ratios ranged between 0.7102 and 0.7134, the ratios of faunal samples from rural Vidzeme were higher, between 0.7131 to 0.7149. In fact, only one child from MG2 had overlapping ratios with the faunal samples from rural Vidzeme and, based on this evidence, it was suggested that the individual might have come from the region. Faunal sample $^{87}Sr/^{86}Sr$ ratios from Vidzeme proved to be significantly different to those of dental enamel and dentine from children in the mass graves, as well as the GC. Consequently, although the sample size was small for this analysis, the results indicated that most children from all three contexts likely represented people of a similar origin, most likely from Gertrude village, inner Riga, and its immediate vicinity. The results of the strontium analysis thus provided a definite answer to research question 4, that individuals in the mass graves and the general cemetery mostly represent people from Riga, rather than rural immigrants from Vidzeme. On the other hand, if individual MG2_516 was indeed from rural Vidzeme, then it is possible that among the local population there might have been a number of rural immigrants from the area buried in one or both mass graves. It was noted, however, that more research is needed to clearly define the local biosphere ranges for inner Riga and parts of rural Vidzeme before the differences in ratios between them can be confirmed. Caution was suggested because firstly, there were significant differences between faunal samples from Riga and all "local" human dentine samples, and secondly, some ratios for “local” children, as well as for one faunal sample from Riga, were only slightly lower than faunal samples from Cesis and Limbazi.

Apart from answering research question 4, this analysis also found that one child from the GC, individual GC_41, probably had come from outside Latvia, and Sweden was suggested as one of the possible countries of origin, based on similar Sr isotope ratios in the north and south of the country (Price et al., 2012). This supports historical information about St Gertrude’s cemetery as the probable final resting place for people who did not belong to any congregation of Riga, including travellers, as discussed in Chapter 2.

One aspect of the analysis of these results focused on contrasting them with data from incremental dentine analysis, discussed above. This was done to explore whether the similar $\delta^{13}C$ profiles observed in several children from the mass graves also yielded narrow $^{87}Sr/^{86}Sr$ isotope ratios, signalling growing up in the same community, and to explore if diet might have influenced the obtained ratios. Contrasting isotope data from incremental dentine and enamel showed that indeed most children with similar $\delta^{13}C$ profiles likely did originate from the same community, as supported by narrow $^{87}Sr/^{86}Sr$ isotope ratios. This was the case for two out of three pairs of individuals (MG1_630 and MG2_103, and MG2_177 and MG2_432). Moreover, it was noted that the ratios of individuals MG2_177 and MG2_432, who had nearly identical $\delta^{13}C$ profiles, only differed by 0.0002, which has been reported in modern siblings (Montgomery 2002: 146). This lead to the suggestion that the children might have been related, although this could only be confirmed by ancient DNA analysis.

On the other hand, the $^{87}Sr/^{86}Sr$ ratios of individuals MG1_83 and MG2_516, who also had similar $\delta^{13}C$ profiles, differed by 0.0016, and overlapped with those from the faunal samples from rural Vidzeme in individual MG2_516. Accordingly, it was suggested that despite similarities in childhood diet, the children might have grown up in different regions. If true, this observation supports the suggestion expressed in Chapter 4 and Section 9.2, that children from native Latvian populations might be indistinguishable by dietary isotope analysis, if they relied on similar food sources across the country. This might have important implications for distinguishing different population groups in the future and indicate that although such analysis might be useful on some occasions, as shown by the obvious differences in $\delta^{15}N$ values between the St Gertrude’s cemetery and Jelgava populations, as discussed above, other means should be employed when comparing contemporary groups of a similar social status. More research, however, would be necessary to confirm if this is the case.

The results of the strontium isotope analysis explain the inconclusive results of dental disease and adult isotope analyses, as well as incremental dentine analysis, with regard to evidence for the presence of different population groups in the cemetery. Indeed, the significant differences in dental attrition scores and calculus deposits between the contexts, as well as similar dietary $\delta^{13}C$ profiles of several individuals from the mass graves, did not provide enough evidence for the presence of rural immigrants in either mass grave. As already mentioned above, the results of the incremental dentine analysis lead to the suggestion that the observed dietary differences between children from the mass graves and the GC might be due to temporal changes in availability of resources, or dietary habits, of the same population, taking into account that the people in the mass graves represent the same generation, while burials in the GC span over more than three centuries. Indeed, differences in dietary habits of this population were expressed in high individual variation of adult $\delta^{13}C$ and $\delta^{15}N$ values, and it is possible that differences in dental wear and calculus were also caused by temporary changes in the availability of certain resources, and the subsequent shift to other resources, for example, substituting finely ground and sieved bread flour with a version which included bran, and other plant material, as discussed in Section 9.2.1 above.

Temporal change in dietary habits was also supported by the strong negative correlation between the mean $\delta^{13}C$ values and $^{87}Sr/^{86}Sr$ isotope ratios in children from mass graves, but not the GC. This was particularly clear in individuals MG1_127, MG2_177, MG2_432 and MG2_508, whose lowest observed $^{87}Sr/^{86}Sr$ isotope ratios in the population were consistent with the highest $\delta^{13}C$ profiles. This was taken as evidence for $^{87}Sr/^{86}Sr$ isotope ratios being probably influenced by marine foods in children from the mass graves, while other factors were likely responsible for the variation in ratios in children from the GC. On the other hand, it was also proposed that children from mass graves might have come from an area closer to the coast, albeit too near to Riga to be distinguishable by strontium isotope analysis. This could be tested by obtaining bioavailable strontium isotope ratios from coastal areas closest to Riga.

Apart from providing crucial evidence for the origin of the St Gertrude’s cemetery population, strontium isotope analysis also showed that regardless of homogenous geology, studying migration through $^{87}Sr/^{86}Sr$ isotope ratios has potential for Latvian populations. This has important implications for future migration studies in Latvia and is the first step towards the creation of a local $^{87}Sr/^{86}Sr$ isotope ratio map. Moreover, the results provide useful comparative data for researchers studying migration in past European populations, previously unavailable from Latvia.

9.3 Evidence for physical health of St Gertrude's cemetery population, and how it compares with other post-medieval populations from Latvia, Lithuania and Estonia

As outlined above, this section explores how research questions 1, 2 and 3 were answered with the help of palaeopathological and comparative analyses. These questions were mainly considered in Chapters 7 and 8. The research questions for this analysis were based on the possibility that there could be poor rural immigrants from Vidzeme buried in the mass graves, as opposed to the population which lived in Gertrude village; although these people were also mostly subsistence farmers, the location of the village less than 1km from inner Riga must have provided them with better access to resources, as discussed in Chapter 2. However, the results of the dental and dietary isotope analyses, and strontium analysis in particular, suggested that most of the people buried in St Gertrude's cemetery represent people from Riga and its vicinity, with some people in the mass graves probably having originated in rural Vidzeme. The mere presence of local people in the mass graves helps answering research question 1, that the frequent wars, famines and epidemics mentioned in historical sources clearly had a devastating effect on the lives of the moderately wealthy St Gertrude's population, and also the population of Riga, taking into account that the victims of plague were also buried in this cemetery, as discussed above.

The presence of people from the local population in the mass graves, however, gave an opportunity to compare evidence for certain aspects of physical health between generations of people who died over several centuries from different causes and were buried in the general cemetery, and people who represent the same generation and died within days or weeks from each other. Accordingly, palaeopathological and comparative analyses were based on contrasting data between these two groups. Research question 1, which deals with evidence for physical health in the St Gertrude's cemetery population, was mainly dealt with in Chapter 7, and will be discussed in Section 9.3.1 below. The analysis primarily focused on evidence for differences in general living conditions between people buried in MGs and the GC, and evidence for higher frailty for people buried in the MGs. Data from all previous analyses were used to aid the discussion. Research questions 2 and 3 were mainly considered in Chapter 8, exploring how the prevalence of certain pathological lesions and stature estimates compare with those recorded in other contemporary urban and rural populations of various social standings from Latvia, Lithuania and Estonia. This was the final aspect of the research and will be discussed in Section 9.3.2.

9.3.1 Evidence for physical health in the St Gertrude's cemetery population

The prevalence of palaeopathological lesions recorded during the skeletal analysis was used with caution to interpret physical health in St Gertrude's population, considering the osteological paradox as well as recent research warning against oversimplifying the interpretation of pathological lesions in archaeological populations (Boldsen and Milner, 2012, DeWitte and Stojanowski, 2015, Wood et al., 1992). Indeed, even though people buried in the mass graves might represent a group of people with higher frailty during mass mortality events, most of those buried in the general cemetery were not physically healthy individuals either, and all three factors outlined by Wood et al. (1992) with regard to the osteological paradox - demographic non-stationarity, selective mortality and heterogeneous frailty - must be considered when comparing both population groups. With the limitations of palaeopathological analysis in mind, Chapter 7 explored the prevalence of cribra orbitalia, linear enamel hypoplasia, upper and lower respiratory infections, evidence for vitamin C and D deficiencies, and non-specific periosteal reactions on long bones, in people buried in St Gertrude's cemetery.

Cribra orbitalia and enamel hypoplasia were taken as evidence for compromised childhood health, given that these lesions can only form in childhood, as outlined in Chapter 2 (Allen et al., 2004, Halvorsen and Bechensteen, 2002, Kent, 1986, Ma'luf et al., 2002, Rajendran, 2009, Stuart-Macadam, 1985, 1992, Tonna, 1974). The lack of significant differences in the prevalence of cribra orbitalia in either adult or non-adult individuals between the two groups, the GC and MGs, indicated a similar pathogen load in childhood. This, in turn, suggests that similar conditions were experienced by most generations of this population, even though it is difficult to identify a single cause for orbital porosity, and genetic or acquired anaemia (Holland and O'Brien, 1997, Lanzkowsky, 1968, Mittler and van Gerven, 1994, Ortner, 2003: 363-4, Oxenham and Cavill, 2010, Ross and Logan, 1969, Stevens et al., 2013, Stuart-Macadam, 1987a, 1987b, 1992), vitamin C deficiency (Ma'luf et al., 2002, Sabet et al., 2001, Saint-Martin et al., 2015, Wapler et al., 2004, Woo and Kim, 1997), and other conditions were considered as the possible aetiologies. The observed significant differences in prevalence between adults and children in both groups, however, suggested the possibility that frailty was higher in children who had developed the lesions, thus increasing their mortality during further episodes of compromised physical health.

The significantly higher prevalence of LEH, and LEH in combination with CO, in children from the MGs, compared to children from the GC, was taken as evidence for a higher frailty of children with previous episodes of arrested growth to mass mortality events. A similar phenomenon was observed in people from a Black Death cemetery from London (DeWitte, 2009, DeWitte and Hughes-Morey, 2012, DeWitte and Wood, 2008). The lack of significant differences in the overall prevalence of either CO or LEH in the adult population suggested that physical health in childhood, and subsequent survival into adulthood, changed little over the generations of this population.

The significantly lower prevalence of multiple LEH lesions in women from the GC compared to men from both groups, was explained as evidence for possible differences in early childhood diet, or weaning practices, of boys and girls in some generations; the current lack of evidence, however, as expressed in no data on the sex of the children, or dietary isotope evidence for weaning in teeth with an earlier age of formation, makes further discussion difficult. It was also taken into account that a higher prevalence of LEH in men might be linked to a weaker immune response in boys compared to girls, making them more susceptible to infections (Eveleth and Tanner, 1990, Grossman, 1985, Kuh et al., 1991, Ortner, 1998).

With regard to upper and lower respiratory tract infections, evidence for possible pulmonary infections was only found in two adult individuals, while the prevalence of maxillary sinusitis was moderate, affecting up to 40% of the population. The lack of significant differences between any of the groups was interpreted as evidence for similar working and living conditions, at least in the adult population. As already mentioned in Chapter 7, evidence from historical and ethnographic sources suggests that most people's homes were subject to poor air quality due to particulate matter in the air from open fires and working in barns with agricultural products would have also exposed these people to increased amounts of dust, potentially leading to chronic sinusitis. Obtaining prevalence data for upper respiratory tract infections in this population was hampered by the small sample size due to most skulls being intact, therefore preventing access to the maxillary sinuses and making them unobservable. A future study using an endoscope would be necessary for more detailed information on maxillary sinusitis in this population.

Moving on to vitamin C and D deficiencies, skeletal analysis revealed a less than 10% prevalence for both conditions in St Gertrude's cemetery population, including evidence for residual rickets in adults. Evidence for vitamin C and D deficiencies was found almost exclusively in children from the general cemetery, compared to just one individual from the mass graves. This was explained by the unequal distribution of children aged from birth to four years, in which the conditions were the most prevalent in both contexts, rather than meaningful differences in prevalence between the two groups (Hess, 1921, Schmorl, 1909, Wimberger, 1925). The presence of scurvy was interpreted as evidence for seasonal deficiency, or a consequence of food shortages due to years of bad harvests, or warfare. This might have also been true for rickets, especially during winters, when the lack of sunshine might have exacerbated dietary deficiency. Alternatively, it was suggested that the lack of evidence for vitamin deficiencies in children from the mass graves might mean that they did develop the conditions, particularly those who died during the famine, but that they died before any lesions in the skeleton formed.

With regard to adults, the more equal number of people with residual rickets in both groups was taken as evidence for the actual prevalence of vitamin D deficiency in St Gertrude's population. The low prevalence, however, complemented data from non-adults, and confirmed that this condition was not a major health problem for the people buried in the cemetery. On the other hand, conclusive evidence for vitamin C deficiency in adults was not obtained, due to the limited skeletal response in mature individuals, as discussed in Chapters 2 and 7 above. It was suggested that while in some individuals, bilateral periosteal reactions on long bones, as well as periodontal disease, might have been the consequence of scurvy, a more definite diagnosis is difficult. Given the lack of evidence for active osteomalacia, as well as the low prevalence of vitamin C and D deficiencies in non-adults, it was assumed that a high prevalence of adult scurvy would be unlikely in this population.

Finally, it was noted that non-specific lesions in non-adults mimicked the prevalence of possible scurvy and rickets, whereby children in the general cemetery were affected significantly more frequently, especially with regard to lesions in the skull. The fact that the prevalence of lesions did not exceeded 15% was explained by the equally low prevalence of vitamin C and D deficiencies, which are also known to cause similar skeletal changes; consequently, in some children, non-specific lesions might be taken as evidence for milder forms, or healing, of vitamin deficiencies, or other conditions, including trauma and infections. In adults, however, the prevalence of non-specific lesions was considerably higher, which was explained by the difficulty of diagnosing a number of specific conditions, including vitamin deficiencies, in mature skeletal remains, compared to children. It was suggested that although there were differences in prevalence of the lesions by age and sex groups, overall both people from the GC and MGs were equally exposed to conditions causing them. Likewise, analysis of possible higher frailty, whereby the prevalence of new woven bone on the long bones, suggestive of an ongoing inflammation, was compared, proved that men from the GC were affected significantly more frequently than men from mass graves, contrary to the findings of DeWitte and Wood (2008) in people from a Black Death cemetery in London, mentioned above.

Altogether, the analysis of physical health in the St Gertrude's population revealed that many aspects of living and working, as expressed in chronic conditions such as maxillary sinusitis, and non-specific periosteal reactions, as well as evidence for compromised childhood health, were similar in both groups, especially with regard to adult individuals. This is not surprising, considering that the living conditions of native Latvian populations remained largely the same for centuries, as discussed in Chapter 2. Likewise, prevalence rates for vitamin C and D deficiencies proved to be low, suggesting adequate nutrition and exposure to sunlight. In children, a degree of heterogeneous frailty was observed, as expressed in significantly higher prevalence rates of CO and LEH in individuals from the mass graves, compared to those buried in the GC. The equal prevalence of these lesions in the adult population, however, suggests that episodes of arrested growth in childhood did not predispose those who had survived into adulthood to increased frailty during mass mortality events. It is hoped that advances in palaeopathological analysis will help to better understand the non-specific lesions in adults observed in this research, to enable a more detailed discussion about the living conditions of this population.

9.3.2 Comparison of evidence for physical health in the St Gertrude's population, and other contemporary cemetery populations from Latvia, Lithuania and Estonia

The final aspect of this research dealt with placing the people buried in St Gertrude's cemetery into a regional context. To achieve this, prevalence rates of dental disease, cribra orbitalia, LEH, and stature estimates in the St Gertrude's cemetery population, were contrasted with other cemetery populations in Latvia, Lithuania and Estonia. The comparative bioarchaeological data was selected based on its ability to reveal information about certain aspects of physical health of populations through skeletal analysis, keeping in mind that the analysis would be limited by the fact that the data has been collected from deceased rather than physically healthy individuals, as discussed above, and the current scarcity of comparable data from other cemetery populations in the region.

Apart from comparative bioarchaeological analysis, Chapter 8 also compared the methods used to estimate age and sex of the individuals, calculate their stature, and record prevalence rates of pathological lesions. The different methods were used for re-calculating prevalence for certain pathological lesions in the St Gertrude's cemetery population, and for comparing the obtained results using statistical tests, to see if different methods would result in significantly different prevalence rates in the same population. Accordingly, this section is further divided into two sub-sections: Section (i) explores the observed differences in methodology used by bioarchaeologists from the three Baltic States; and Section (ii) deals with comparative analysis of bioarchaeological data obtained from the cemetery populations.

(i) Differences in methodology for recording and presenting bioarchaeological data in Latvia, Lithuania and Estonia

After comparing data from Latvian, Lithuanian and Estonian populations, the study concluded that most researchers had used age and sex estimation methods detailed in Buikstra and Ubelaker (1994: 16-38). For children in St Gertrude's cemetery, a narrower age range was achieved by using AlQahtani et al. (2010), as detailed in Chapter 3. Since most studies did not divide children by detailed age categories, the small differences in age ranges achieved by the two methods did not cause any discrepancies for the comparative analysis. Likewise, stature estimates had mostly been obtained, using Trotter and Gleser (1952) and in addition, methods developed for the local populations (Gerhards, 2005a).

On the other hand, recording prevalence for pathological lesions proved to vary considerably between the researchers. Criteria for inclusion of individuals for analysis, and prevalence calculations, differed for caries, antemortem tooth loss and linear enamel hypoplasia between individual researchers from Estonia and Latvia. Testing prevalence calculations using several methods in St Gertrude's cemetery population revealed no statistically significant differences in the obtained prevalence rates for any condition. It was noted, however, that using methods which only include individuals with a certain number of teeth present for the observation of dental disease, might considerably reduce the number of observable individuals in skeletal populations with high rates of ante- or post-mortem tooth loss. This, in turn, might result in significant differences in estimated prevalence rates, if compared to a population where all individuals with any number of teeth present, had been classed as observable for analysis.

The presentation of data also differed considerably, and this proved to be a more significant problem. Comparing prevalence of LEH by sex group, and in children and adults, was only possible between three Latvian, and one Lithuanian population. Only total prevalence was given for the other four populations included in the comparative analysis. Likewise, the lack of data for observed and affected individuals for the analysis of cribra orbitalia in Estonian populations prevented meaningful comparisons with the St Gertrude's cemetery population.

A similar problem was observed with regard to stature estimates: while the methods used were comparable, the lack of information about the number of individuals studied, as well as the standard deviation of the mean estimates in Lithuanian and Estonian populations, meant that comparative analysis using statistical significance testing, was only possible between Latvian populations.

To conclude, the study suggested that different methods would not be a significant problem for bioarchaeological cross-population analyses, if the inclusion criteria were clearly defined, and the number of both observed and affected individuals and skeletal elements were presented in the publication. Including data by age (adults and children) and sex for certain pathological analyses would enable more detailed comparative studies between the populations. The analysis of data that could be compared, however, highlighted differences in some aspects of living conditions in different post-medieval populations. The results of this analysis will be discussed in the next section.

(ii) Living conditions in the St Gertrude's cemetery population, and other contemporary populations from Latvia, Lithuania and Estonia

As already mentioned above, this study was able to compare dental disease, LEH, cribra orbitalia, and stature estimates in the St Gertrude's cemetery population, with several contemporary populations. The data on stature estimates in St Gertrude's population was presented for the first time in Chapter 8.

With regard to dental disease, detailed data on caries was available from seven comparative populations, and data on periapical lesions and AMTL from five, allowing for a meaningful comparative analysis. The lack of statistically significant differences in the prevalence of caries, periapical lesions and ante-mortem tooth loss between people from the GC and MGs was explained by a similar amount of carbohydrates, particularly bread, in their diet, as already discussed in Chapter 4 and Section 9.2.1 above. This proved to be true for most other comparative populations of a similar social status from the region, when compared to people from St Gertrude's cemetery. An exception was women from the GC and Tääksi populations, whereby the significantly higher prevalence in the Estonian population was explained by possible differences in dietary practices. The uniformity in caries prevalence in all other groups of low-moderate social status, compared to the St Gertrude's population, was explained by the fact that according to historical sources, bread was a staple dietary source not only for the native Latvian populations, but also those living in Estonia and

Lithuania (Dumpe, 1999: 122-7, Hueck, 1845, Hupel, 1774-1782, Laidre, 1999, Limbo, 2009, Straumīte, 1906). Significant differences, however, emerged when comparing females from St Gertrude's cemetery, and high-status females from the Jelgava population (JHTCC), with the wealthier females having significantly higher caries rates. In men, however, differences in social status did not seem to affect their dental health. The higher caries rates in women from Jelgava were explained by the availability of refined sugar, while differential diet for sex groups in high status populations was proposed as one of the possible explanations for the lack of such differences in men.

With regard to evidence for disrupted growth, the results of this analysis are limited; while comparative data about LEH were gathered from six comparative populations, prevalence in children and adults, and males and females separately, was only available from two other populations. The scarcity of detailed data makes understanding of how growth disruption affected different demographic groups in post-medieval Baltic populations difficult. Nevertheless, the obtained data showed that the prevalence of LEH in the comparative populations proved to be similar to that in the St Gertrude's population, whereby more than 60% of adults were affected, while the lesions were found in less than 30% of observable children, except for children from the MGs. This was explained by the probability that while most individuals experienced periods of growth disruption during childhood, many were able to survive into adulthood. On the other hand, the lower prevalence of lesions in children might suggest that they succumbed to similar episodes of arrested growth, and died before developing the lesions, as already discussed in Chapters 7 and 8 in relation to the osteological paradox (Wood et al., 1992). The high prevalence of LEH in children from the MGs has already been discussed above in Chapter 7 and Section 9.3.1.

Detailed data on cribra orbitalia, which was taken as evidence for compromised physical health in childhood, as discussed in Chapters 2 and 7, and Section 9.3.1, were available from eight comparative Latvian and Lithuanian populations, making this the most informative analysis of the study. Prevalence rates proved to be more varied in men, compared to women, and non-adult populations also showed considerable variation. The highest prevalence rates were observed in people from urban populations, while no patterns emerged with regard to groups of high and low-moderate social status. Less than 40% of adult populations were affected, but the lesions were more prevalent in all non-adults and ranged from 21.4% to 57.6%. This was interpreted as indicative of considerable variation in pathogen load in each region and even city, also taking into account that the bone changes of cribra orbitalia can be caused by a number of conditions, including anaemia, scurvy, and trauma, as detailed in Chapter 2. Likewise, as already discussed with regard to CO in the St

Gertrude's population, it was suggested that the higher variation in prevalence in men could have been the result of differences in immune response, compared to women (Klein and Flanagan, 2016, vom Steeg and Klein, 2016); and that the overall higher CO rates in children might indicate a degree of heterogeneous frailty, whereby the risk of mortality increased in children who had developed the lesions. The study also suggested that recording porotic hyperostosis, similar porotic lesions in the skull vault, might help to achieve a better differential diagnosis in future studies. Likewise, employing ancient DNA analysis for non-adult sex estimation would enable studies of differential mortality of affected boys and girls in childhood.

The final aspect of this study was comparison of stature estimates. As pointed out in Section (i) above, the study was hampered by a lack of detailed comparative data from Estonian and Lithuanian populations, resulting from differential data presentation methods, and only the stature of populations from Latvia could be meaningfully compared. Nevertheless, the study revealed that people from high-status populations were taller than those from low-moderate status populations, but the differences were only statistically significant in males. It was suggested that the observed pattern in men was most likely the result of differential access to resources in these populations; as discussed in Chapter 2, shorter stature is associated with limited access to resources in modern populations (Alderman et al., 2006, De Onis and Blössner, 2003, Guerrant et al., 2008). The slightly shorter stature of men from the MGs, compared to the GC, was explained by a possible period of compromised access to resources for this generation. Although the differences were not statistically significant between the two contexts, they resulted in men from the MGs being significantly shorter than those in three out of four high-status populations, unlike men from the GC. On the other hand, it was also suggested that males from the MGs might represent a group of people who had experienced growth failure in early childhood, which negatively affected their adult stature (Stein et al., 2010, Victora et al., 2010); consequently, this might have predisposed them to increased frailty during mass mortality events, as also observed in a Black Death cemetery from London (DeWitte and Hughes-Morey, 2012).

In women the lack of significant differences was explained by a more robust immune response to environmental conditions, compared to men, which would also be reflected in stature variations (Eveleth and Tanner, 1990, Grossman, 1985, Jørkov, 2015, Kuh et al., 1991, Ortner, 1998). The systematically shorter stature of women compared to men was found to be consistent with other studies from both, archaeological, and modern populations from low-income countries (Addo et al., 2013, Gerhards, 2005a, Koepke and Baten, 2005).

Together, the comparative analysis highlighted the importance of standardised data presentation in bioarchaeological studies, in order to enable comparisons using statistical significance tests, thus increasing credibility of similar comparative analyses in the future. The data that could be compared, revealed similar dental disease rates for most low-moderate status populations, signalling similar dietary practices, while evidence for compromised physical health in childhood, as expressed in linear enamel hypoplasia and cribra orbitalia, seemed to vary between communities, regardless of social status, or living environment. Adult stature, however, proved to be higher in high-status than low-moderate status groups, although it was only expressed in males.

9.4 Future potential

Apart from achieving its aims and objectives, each aspect of this research has revealed considerable potential for future studies. First, one way of obtaining more detailed information about diet in St Gertrude's population would be carrying out microscopic analysis of dental calculus, which could reveal the composition of dietary carbohydrates used by these people, including type of grains used (wheat, rye, etc.). Similar research has indicated that starch grains are abundant in calculus from archaeological teeth (Boyadjian et al., 2007, Lalueza Fox et al., 1994, Salazar-García et al., 2013), and helped to shed light on oral health, dietary patterns and importantly, changes in diet in several archaeological populations (e.g. Adler et al., 2013, Hardy et al., 2012, Henry and Piperno, 2008). Contrasting this data between people from the mass graves and the general cemetery would help to further explore short-term dietary strategies employed by the people buried in mass graves, particularly MG1 who, according to evidence from incremental dentine, might have been the victims of a famine. Moreover, calculus is also rich in ancient bacterial DNA, more so than bone, which holds the potential for testing for the presence of particular bacteria in the St Gertrude's population (particularly the people buried in mass graves), including those causing leprosy, plague, and TB (Preus et al., 2011, Weyrich et al., 2015).

Second, the significant differences observed in carbon and nitrogen isotope values between people from the St Gertrude's cemetery, and children from the high-status Jelgava population, call for contrasting dietary isotope data between cemetery populations of differential social status. The current study failed to observe meaningfully different context-specific isotope values because most people were likely of a similar origin, as suggested by Sr isotope analysis, and it was hypothesised that diet of the native populations might have been similar across the region, as shown by similar incremental dentine dietary profiles in children who likely originated from Riga, and a child from Vidzeme. Studies with larger sample sizes from cemetery populations of known social status would be necessary to further explore the dietary differences between them. In support of this hypothesis, current data from late - post-medieval populations from Tallinn, Estonia, and the nearby rural village of Kaberla, point to largely similar diets for the local Estonian people in both urban and rural environments, with individual rather than site-specific variation in carbon and nitrogen isotope values, while two individuals of a higher social status, who were probably immigrants, showed clear differences, as expressed in higher isotope values (Lightfoot et al., 2016).

Third, the probability that people buried in the mass graves represent the victims of a mass mortality event, opens opportunities for further studies, exploring higher frailty by contrasting prevalence rates and co-occurrence of various other pathological conditions in this group with the general cemetery, or other cemetery populations. Higher frailty in this group was already demonstrated in the current study and was particularly evident for children; this could be studied in more detail, by taking into account the age, and adult stature and sex, as has already been successfully employed by DeWitte and co-workers (2009, 2010, 2011, 2012). Moreover, the probability that people in MG1 were the victims of a famine could be further explored by more detailed incremental dentine analysis, particularly using deciduous teeth because of their considerably shorter duration of formation and consequently, a greater potential for observing short-term variations in diet (Beaumont et al., 2015).

Finally, Sr isotope analysis carried out during this research has opened potential for migration studies in Latvia, having demonstrated significant regional differences in biologically available Sr ratios from Riga and rural Vidzeme. The full potential of Sr isotope data in Latvia is yet to be explored; for example, it is not currently known if regions other than rural Vidzeme would also yield significantly different bioavailable Sr isotope ratios; and how varied a Sr isotope map of Latvia would be, considering the largely monolithic underlying geology. The ratios obtained by the current study, however, provide readily usable comparable data for migration studies in the wider Baltic region and Europe, previously unavailable from Latvia. Altogether, the demographic, palaeopathological and isotopic data in this research have been gathered and presented with an aim to make them easily comparable. This is of particular importance, given the scarcity of such wide data sets from the region currently available in English and thus, accessible globally to researchers studying archaeological populations.

Appendix 1. Results of radiocarbon analysis

Table A1. Results of radiocarbon analysis on human bone samples

ID	Sample	OxA	Date	+/-	Used	Yield	%Yld	Excess	%C	$\delta^{13}C$	$\delta^{15}N$	CN
MG1_645	bone	32,209	380	24	620	93.63	15.1	88.65	46.5	-19.8	10.7	3.2
MG1_488*	bone	34,418	353	27	580	87.87	15.2	82.97	42.4	-20.6	10.6	3.2
MG2_687	bone	32,280	326	24	610	86.5	14.2	81.54	44.6	-20.2	10.1	3.1
GC_676	bone	32,258	646	30	600	78.58	13.1	64.09	45.7	-19.5	14.2	3.2

*Analysed in a separate batch

Table A2. Calibrated radiocarbon dates assuming no marine input into diet (all dates in AD)

ID	OxA	Date	+/-	68.2% probability range			95.4% probability range		
				from	to	%	from	to	%
MG1_645	32,209	380	24	1450 1600	1520 1620	53.3 14.9	1440 1570	1530 1630	67.5 27.9
MG1_488*	34,418	353	27	1470 1570	1530 1630	32.6 35.6	1450 1540	1530 1640	43.7 51.7
MG2_687	32,280	326	24	1510 1610	1600 1640	55.2 13.1	1480	1650	95.4
GC_676	32,258	646	30	1290 1350	1320 1390	28.4 39.8	1280 1340	1330 1400	42.5 52.9

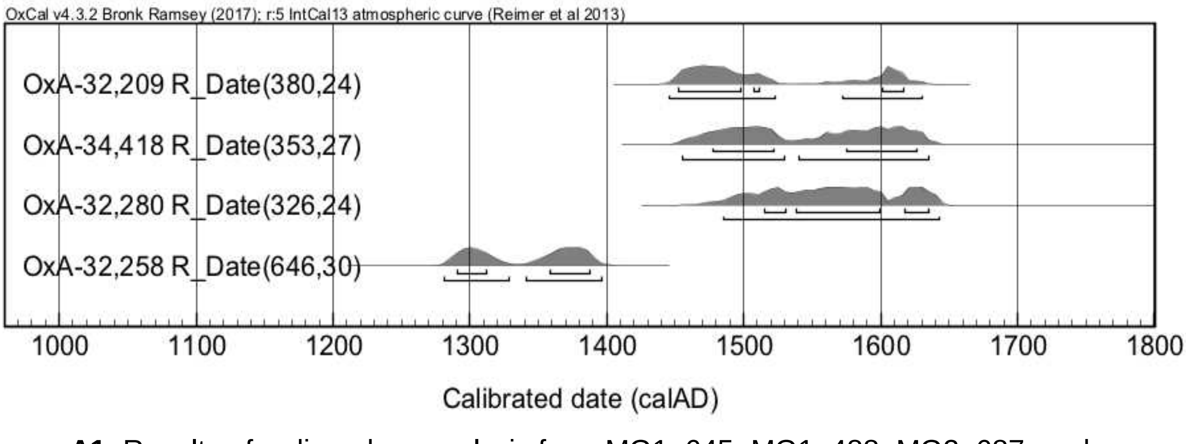

Figure A1. Results of radiocarbon analysis from MG1_645, MG1_488, MG2_687, and GC_676, assuming no marine input into diet

Appendix 2. Supplementary Material S4

Table S4.5. Results of statistical analysis for dental attrition, dental disease, and isotope analysis

Groups tested	Context	Test used	Statistics	P value
Dental attrition				
Females	GC, MG1, MG2	Kruskal-Wallis	N=79, H=1.49, df=2	p=0.475
Males			N=115, H=10.94, df=2	p=0.004*
Young males	GC, MG1, MG2	Kruskal-Wallis	N=49, H=8.62, df=2	p=0.013*
Young males	GC, MG1	Mann-Whitney^	N=37, U= 237.5, z=-2.01	p=0.044*
	GC, MG2		N=31, U=180, z=-2.66	p=0.008*
Older males	GC, MG1, MG2	Kruskal-Wallis	N=66, H=2.69, df=2	p=0.2605
Males, females	GC	Mann-Whitney	N=69, U=585.5, z=0.07	p=0.944
	MG1		N=71, U=336.5, z=2.76	p=0.006*
	MG2		N=54, U=159, z=3.45	p=0.001*
Young males, females	MG1	Mann-Whitney^	N=33, U=124, z=0.38	p=0.704
	MG2		N=20, U=12.5, z=2.7	p=0.007*
Older males, females	MG1		N=38, U=66, z=2.2	p=0.028*
	MG2		N=34, U=59.5, z=2.86	p=0.004*
Children	GC, MG1, MG2	Kruskal-Wallis	N=72, H=7.59 df=2	p=0.022*
Children	MG1, GC	Mann-Whitney^	N=57, U=248.5, z=2.43	p=0.015*
	MG1, MG2		N=47, U=148.5, z=2.08	p=0.037*
Caries				
Males, females	GC	Chi-Square	N=84, χ^2=3.02, df=1	p=0.082
Children	GC, MG1, MG2		N=164, χ^2=5.81, df=2	p=0.054
Periapical lesions				
Males, females	MG2	Chi-Square	N=61 χ^2=3.49, df=1	p=0.062
Calculus deposits				
Females	GC, MG1	Fisher Exact	N=60	p=0.281
	GC, MG2		N=53	p=0.038*
Children	GC, MG1	Chi-Square	N=135; χ^2=22.28, df=1	p<0.001*
	GC, MG2		N=121 χ^2=19.82, df=1	p<0.001*
Isotope analysis				
$\delta^{15}N$				
Males	GC, MG1, MG2	Kruskal-Wallis	N=56, H=2.72, df=2	p=0.257
Females			N=39, H=2.83, df=2	p=0.243
Males, Females	GC	Mann-Whitney	N=51, U=218.5, z=1.76	p=0.078
	MG1		N=21, U=42, z=0.88	p=0.379
	MG2		N=23, U=73.5, z=-0.84	p=0.401

δ¹³C				
Males	GC, MG1, MG2	Kruskal-Wallis	N=56, H=4.6, df=2	p=0.101
Females	GC, MG1, MG2	Kruskal-Wallis	N=39, H=6.93, df=2	p=0.031*
	GC, MG1	Mann-Whitney^	N=31, U=171.5, z=-2.52	p=0.012*
	GC, MG2		N=28, U=97.5, z=-0.86	p=0.390
	MG1, MG2		N=19, U=25, z=1.53	p=0.126
Males, Females	GC	Mann-Whitney	N=51, U=165, z=2.79	p=0.005*
	MG1		N=21, U=25, z=2.08	p=0.037*
	MG2		N=23, U=55, z=0.29	p=0.772

*-statistically significant difference; ^-post-hoc test

Table S4.6. Prevalence of caries, periapical lesions, periodontal disease and AMTL by affected/observed individuals and tooth/quadrant/alveolus count in young and older adults

	By individual				By tooth			
	Young		Older		Young		Older	
	Males	Females	Males	Females	Males	Females	Males	Females
	Caries							
GC	8/19	2/14	19/25	14/26	13/457	7/280	59/464	34/413
MG1	8/18	8/16	18/34	9/13	16/403	13/348	40/711	35/253
MG2	4/13	4/8	15/22	10/17	7/308	5/206	41/442	26/307
	Periapical lesions							
GC	2/19	2/14	16/25	12/26	2/546	2/346	40/739	22/668
MG1	3/18	1/16	16/34	9/13	3/517	1/439	37/1001	23/408
MG2	2/13	1/8	18/23	6/17	4/369	1/246	34/663	17/498
	Periodontal disease							
GC	3/19	2/14	15/25	9/26	10/143	10/93	75/183	42/172
MG1	2/18	3/16	18/34	7/13	7/138	13/116	113/267	32/104
MG2	4/13	1/8	12/23	8/17	11/99	8/64	50/171	39/125
	AMTL							
GC	3/19	5/14	20/25	20/26	4/546	7/346	133/739	128/668
MG1	4/18	5/16	27/34	12/13	6/517	6/439	121/1001	71/408
MG2	4/13	2/8	17/23	14/17	7/369	4/246	80/663	104/498

Table S4.7. Prevalence of calculus deposits in adult individuals by affected/observed individuals/tooth count

By individual						
	Males			Females		
	GC	**MG1**	**MG2**	**GC+3M**	**MG1**	**MG2**
Calc	43/44	51/52	35/35	32/40	28/29	21/25
Calc2	12/43	11/51	12/35	3/32	6/28	7/21
By tooth						
Calc	535/922	650/1114	548/750	381/693	308/601	319/513
Calc2	27/535	31/650	59/548	8/381	21/308	13/319

Calc1 – slight deposits; Calc2 – medium-heavy deposits

Table S4.8. Prevalence of calculus deposits in non-adult individuals by affected/observed individual/tooth count

By individual									
	Deciduous/total			Permanent/total			Total		
	GC	MG1	MG2	GC	MG1	MG2	GC	MG1	MG2
Calc	9/95	4/40	9/26	13/95	24/40	13/26	20/95	26/40	18/26
Calc2	0	1/4	0	0/13	1/24	3/13	0/20	1/26	3/18
By tooth									
Calc	31/744	7/150	32/171	98/376	140/630	132/302	129/1120	148/780	165/473
Calc2	0/31	1/7	0/32	0/98	3/140	6/132	0/129	4/148	6/165

Calc – calculus present; Calc2 – medium-heavy deposits

Table S4.9. Details of measurement data for $\delta^{15}N$ and $\delta^{13}C$ isotopes

	Sample ID	Wt coll. mg	$\delta^{15}N$ ‰	Wt %N	$\delta^{13}C$ ‰	Wt %C	C/N atomic	% coll. yield
1	3M692 a	0.544	10.6	15.6	-20.7	42.6	3.19	19.3
2	3M692 b	0.575	10.6	16.0	-20.7	43.0	3.14	
3	3M697 a	0.562	10.3	15.9	-20.9	42.8	3.14	16.8
4	3M697 b	0.658	10.3	15.9	-20.8	42.8	3.14	
5	3M700 a	0.550	11.1	15.5	-20.6	42.4	3.20	15.7
6	3M700 b	0.554	11.2	15.5	-20.6	42.4	3.18	
7	3M701 a	0.572	9.7	15.8	-21.2	42.8	3.16	18.1
8	3M701 b	0.530	9.9	15.9	-21.2	42.8	3.13	
9	3M706 a	0.546	10.8	15.3	-20.8	42.7	3.25	17.2
10	3M706 b	0.770	10.7	15.7	-20.6	42.6	3.17	
11	K4 a	0.527	9.6	15.4	-20.4	41.7	3.16	12.7

12	K4 b	0.499	9.7	15.5	-20.4	42.0	3.16	
13	K5 a	0.529	11.5	15.5	-20.1	42.1	3.17	14.4
14	K5 b	0.509	11.1	15.4	-20.1	41.7	3.17	
15	K26 a	0.573	11.2	15.4	-20.2	42.1	3.18	14.1
16	K26 b	0.569	11.0	15.2	-20.2	41.8	3.20	
17	K30 a	0.561	12.4	15.4	-20.1	42.3	3.21	10.1
18	K30 b	0.612	12.3	15.3	-20.2	41.9	3.19	
19	K31 a	0.520	11.7	15.3	-19.8	42.8	3.26	10.3
20	K31 b	0.647	11.6	15.5	-19.5	42.4	3.19	
21	K37 a	0.523	10.9	15.3	-19.9	42.2	3.21	14.1
22	K37 b	0.611	10.8	15.6	-20.0	42.8	3.21	
23	K40 a	0.507	8.7	15.3	-20.7	41.5	3.16	10.9
24	K40 b	0.517	8.7	15.6	-20.8	42.2	3.16	
25	K43B a	0.668	9.1	15.6	-21.1	42.4	3.18	13.7
26	K43B b	0.504	9.0	15.4	-21.1	42.0	3.17	
27	K51 a	0.570	11.4	15.1	-20.3	42.4	3.29	15.7
28	K51 b	0.746	11.3	15.6	-20.1	42.3	3.16	
29	K53 a	0.543	12.5	15.4	-19.9	42.3	3.20	16.1
30	K53 b	0.635	12.4	15.5	-19.9	42.3	3.18	
31	K67 a	0.587	11.1	15.4	-19.9	42.3	3.20	8.0
32	K67 b	0.540	11.0	15.3	-19.9	42.1	3.22	
33	K69 a	0.643	11.1	3.3	-20.3	9.4	3.33	15.2
34	K69 b	0.566	11.3	15.5	-20.4	42.3	3.19	
35	K78 a	0.572	11.8	15.4	-20.0	42.4	3.21	18.3
36	K78 b	0.612	11.7	15.6	-19.9	42.4	3.16	
37	K87 a	0.620	12.8	15.7	-19.9	42.3	3.15	16.7
38	K87 b	0.572	12.8	15.6	-20.0	42.5	3.18	
39	K88 a	0.612	11.0	15.3	-20.3	41.9	3.19	9.0
40	K88 b	0.587	11.0	15.5	-20.3	42.1	3.17	
41	K92 a	0.551	13.7	15.2	-19.1	41.6	3.19	8.6
42	K92 b	0.549	13.7	15.5	-19.1	41.7	3.14	
43	K95 a	0.619	12.5	15.3	-20.0	41.6	3.18	11.2
44	K95 b	0.758	12.4	15.6	-20.1	42.4	3.17	
45	K95.2a*	0.602	12.3	15.2	-20.1	41.7	3.19	11.6
46	K95.2b*	0.717	12.3	15.3	-20.1	41.4	3.15	
47	K96 a	0.509	12.6	15.2	-20.0	41.9	3.21	9.4
48	K96 b	0.536	12.3	15.6	-20.0	42.5	3.17	
49	K100 a	0.614	9.9	15.5	-20.4	42.1	3.17	13.5
50	K100 b	0.571	9.8	15.6	-20.4	42.2	3.16	
51	K113 a	0.603	12.4	15.4	-20.0	41.8	3.18	10.9
52	K113 b	0.574	12.4	15.4	-20.1	41.9	3.18	

53	K114 a	0.687	10.4	15.2	-21.0	41.5	3.19	13.8
54	K114 b	0.790	10.3	15.5	-21.0	41.6	3.13	
55	K115 a	0.511	12.4	15.3	-18.9	42.2	3.21	14.6
56	K115 b	0.634	12.3	15.6	-18.9	42.3	3.16	
57	K135 a	0.602	9.7	15.5	-21.2	42.0	3.17	15.8
58	K135 b	0.594	9.6	15.6	-21.1	42.3	3.16	
59	K160 a	0.539	12.9	14.9	-19.7	41.3	3.23	13.5
60	K160 b	0.504	12.9	15.2	-19.7	41.9	3.21	
61	K187 a	0.556	12.2	15.4	-19.7	41.9	3.17	13.0
62	K187 b	0.601	12.1	15.6	-19.7	42.2	3.16	
63	K191 a	0.529	9.2	15.3	-21.0	42.1	3.21	9.3
64	K191 b	0.536	9.0	15.6	-21.2	42.6	3.19	
65	K234 a	0.563	11.1	15.4	-19.9	42.2	3.20	15.1
66	K234 b	0.609	11.1	15.9	-19.8	42.7	3.14	
67	K235 a	0.506	11.7	15.3	-20.1	41.6	3.17	8.5
68	K235 b	0.599	11.4	15.5	-20.2	41.8	3.15	
69	K262 a	0.556	11.1	15.6	-20.2	42.4	3.18	16.1
70	K262 b	0.580	11.1	15.9	-20.1	42.8	3.14	
71	K310 a	0.535	10.0	15.3	-20.6	41.9	3.19	12.4
72	K310 b	0.516	10.2	15.6	-20.6	42.1	3.14	
73	K321 a	0.501	12.4	15.0	-20.4	41.9	3.25	6.1
74	K321 b	0.599	12.2	15.3	-20.6	42.8	3.27	
75	K323 a	0.558	10.7	15.4	-20.8	41.9	3.17	6.7
76	K323 b	0.526	10.6	15.5	-20.8	41.9	3.16	
77	K342 a	0.522	12.0	15.3	-19.6	42.3	3.22	15.1
78	K342 b	0.551	12.0	15.6	-19.6	42.6	3.18	
79	K394 a	0.517	10.9	15.4	-20.5	42.0	3.18	12.6
80	K394 b	0.528	10.8	15.6	-20.5	42.4	3.17	
81	K410 a	0.506	10.7	15.3	-20.6	41.7	3.17	9.9
82	K410 b	0.508	10.7	15.5	-20.6	41.9	3.15	
83	K427 a	0.569	12.3	15.5	-19.4	42.3	3.19	9.6
84	K427 b	0.526	12.2	15.6	-19.5	42.2	3.16	
85	K462 a	0.501	10.9	15.4	-20.6	42.1	3.19	11.0
86	K462 b	0.516	10.8	15.7	-20.6	42.4	3.15	
87	K539 a	0.528	11.0	15.6	-20.6	42.9	3.21	11.8
88	K539 b	0.526	11.1	15.6	-20.6	42.4	3.16	
89	K557 a	0.559	11.7	15.5	-20.4	42.1	3.18	12.0
90	K557 b	0.505	11.6	15.5	-20.4	42.2	3.17	
91	K617 a	0.553	12.1	15.4	-19.5	41.9	3.17	10.1
92	K617 b	0.547	12.1	15.7	-19.7	42.3	3.15	
93	K631 a	0.570	10.6	15.5	-21.1	42.6	3.20	12.5

94	K631 b	0.671	10.6	15.2	-21.2	41.1	3.15	
95	K638 a	0.631	10.0	16.1	-20.9	43.4	3.15	15.0
96	K638 b	0.628	10.1	15.4	-20.9	41.1	3.12	
97	K639 a	0.753	10.0	15.5	-21.1	42.2	3.18	15.9
98	K639 b	0.771	9.8	15.4	-21.2	41.5	3.15	
99	K676 a	0.700	12.2	15.8	-20.2	42.6	3.15	10.2
100	K676 b	0.752	12.2	15.7	-20.2	41.9	3.12	
101	K677 a	0.606	10.6	15.4	-20.8	41.8	3.16	9.3
102	K677 b	0.596	10.6	15.1	-21.0	42.1	3.24	
103	K683 a	0.547	10.9	15.4	-21.1	42.7	3.23	6.9
104	K683 b	0.731	10.7	15.5	-21.1	42.1	3.16	
105	DA84 a	0.529	11.4	15.9	-21.0	43.9	3.22	11.7
106	DA84 b	0.553	11.4	15.8	-20.8	43.1	3.18	
107	DA84.2 a*	0.623	11.5	16.0	-20.7	43.4	3.15	11.6
108	DA84.2 b*	0.725	11.4	15.9	-20.7	43.0	3.15	
109	DA94 a	0.833	11.4	15.6	-20.5	42.5	3.19	5.8
110	DA94 b	0.639	11.3	15.5	-20.4	42.6	3.20	
111	DA110 a	0.634	10.8	15.7	-20.5	42.8	3.18	16.1
112	DA110 b	0.660	10.8	15.3	-20.5	41.2	3.14	
113	DA111 a	0.572	9.4	15.7	-20.8	43.0	3.17	13.9
114	DA111 b	0.520	9.4	15.6	-20.9	43.1	3.19	
115	DA112 a	0.524	11.5	15.7	-20.3	42.3	3.15	14.0
116	DA112 b	0.539	11.5	19.1	-20.3	51.4	3.13	
117	DA131 a	0.521	12.3	15.6	-19.8	42.4	3.16	9.8
118	DA131 b	0.656	12.3	12.1	-19.8	32.9	3.16	
119	DA139 a	0.522	12.6	19.0	-19.0	50.8	3.12	9.7
120	DA139 b	0.514	12.4	15.4	-19.6	41.2	3.13	
121	DA140 a	0.616	11.3	15.7	-20.3	42.4	3.14	16.1
122	DA140 b	0.503	11.3	18.4	-20.4	49.2	3.12	
123	DA143 a	0.552	11.5	15.6	-20.4	42.5	3.18	16.6
124	DA143 b	0.585	11.4	13.5	-20.5	37.1	3.20	
125	DA147 a	0.573	11.5	15.8	-20.3	42.7	3.16	15.7
126	DA147 b	0.510	11.4	17.2	-20.3	46.6	3.17	
127	DA153 a	0.701	9.9	15.8	-21.0	42.2	3.13	11.9
128	DA153 b	0.558	9.9	14.8	-21.0	39.8	3.13	
129	DA157 a	0.593	11.5	15.7	-20.3	42.6	3.16	11.3
130	DA157 b	0.527	11.4	20.6	-20.3	55.6	3.16	
131	DA163 a	0.564	11.9	15.6	-20.3	42.3	3.17	16.7
132	DA163 b	0.691	11.8	12.8	-20.3	34.5	3.14	
133	DA165 a	0.633	10.4	15.7	-20.9	42.2	3.14	11.9
134	DA165 b	0.566	10.4	17.3	-20.9	46.6	3.14	

135	DA182 a	0.522	10.7	15.6	-20.4	42.4	3.16	14.6
136	DA182 b	0.519	10.9	15.7	-20.4	42.1	3.14	
137	DA338 a	0.532	11.5	15.6	-20.1	42.2	3.15	10.8
138	DA338 b	0.525	11.6	16.0	-20.0	42.2	3.08	
139	DA488 a	0.538	10.2	15.6	-20.7	42.0	3.14	9.6
140	DA488 b	0.534	10.4	15.8	-20.7	42.1	3.11	
141	DA586 a	0.593	9.5	15.6	-20.7	42.2	3.16	12.9
142	DA586 b	0.570	9.7	15.5	-20.7	41.8	3.14	
143	DA622 a	0.511	11.3	15.6	-19.9	42.2	3.16	12.1
144	DA622 b	0.510	11.3	15.6	-19.9	41.8	3.13	
145	DA623 a	0.620	11.4	15.7	-20.1	42.2	3.14	10.8
146	DA623 b	0.600	11.5	15.8	-20.0	41.7	3.08	
147	DA623.2 a*	0.514	11.3	15.7	-20.1	42.4	3.15	16.8
148	DA623.2 b*	0.556	11.3	15.6	-20.3	42.3	3.16	
149	DA645 a	0.656	12.0	15.5	-20.1	42.3	3.18	15.9
150	DA645 b	0.520	12.2	15.7	-20.1	42.2	3.13	
151	DA658 a	0.617	11.9	16.3	-19.9	44.6	3.20	18.2
152	DA658 b	0.664	11.8	15.8	-19.8	42.2	3.12	
153	J15 a	0.668	15.3	16.3	-19.9	44.1	3.16	15.8
154	J15 b	0.583	15.4	16.0	-19.8	43.3	3.16	
155	J22 a	0.738	13.5	16.0	-20.2	43.2	3.14	20.6
156	J22 b	0.732	13.5	16.0	-20.4	43.8	3.19	
157	J33 a	0.685	14.7	16.1	-19.7	44.4	3.21	14.1
158	J33 b	0.620	14.8	15.8	-19.6	43.0	3.17	
159	J40 a	0.592	13.6	13.6	-20.6	42.5	3.65	2.9
160	J40 b	0.621	13.6	14.0	-20.4	42.5	3.55	
161	J95 a	0.653	14.0	15.8	-19.8	43.5	3.21	11.3
162	J95 b	0.700	13.9	15.8	-19.6	43.4	3.20	
163	J97 a	0.513	14.1	15.6	-20.1	43.9	3.28	8.6
164	J97 b	0.752	14.1	15.8	-20.0	43.5	3.21	
165	J98 a	0.639	13.5	16.2	-19.8	44.6	3.21	16.0
166	J98 b	0.579	13.5	16.0	-19.6	42.9	3.12	
167	ZR35 a	0.540	11.2	15.6	-20.5	42.9	3.20	14.5
168	ZR35 b	0.537	11.0	15.8	-20.4	42.4	3.14	
169	ZR42 a	0.587	10.6	15.4	-20.7	42.1	3.18	11.0
170	ZR42 b	0.533	10.6	15.5	-20.6	42.0	3.16	
171	ZR105 a	0.570	9.4	15.3	-20.9	42.4	3.24	10.8
172	ZR105 b	0.562	9.4	15.8	-20.8	42.8	3.16	
173	ZR118 a	0.514	10.9	15.4	-20.3	42.2	3.19	15.9
174	ZR118 b	0.523	10.8	15.8	-20.2	42.3	3.13	
175	ZR123 a	0.586	11.0	15.2	-20.9	42.9	3.28	10.4

176	ZR123 b	0.528	10.9	15.3	-20.6	42.4	3.23	
177	ZR159 a	0.571	10.8	15.7	-20.8	42.5	3.15	16.7
178	ZR159 b	0.518	10.7	15.6	-20.8	42.3	3.16	
179	ZR170 a	0.578	12.1	15.7	-19.3	42.3	3.14	17.7
180	ZR170 b	0.507	12.1	15.9	-19.3	42.6	3.13	
181	ZR197 a	0.538	11.2	15.8	-20.5	42.9	3.17	18.0
182	ZR197 b	0.532	11.1	15.7	-20.4	42.6	3.16	
183	ZR203 a	0.566	11.1	15.9	-20.5	43.4	3.19	13.9
184	ZR203 b	0.686	11.0	15.5	-20.6	42.1	3.18	
185	ZR204 a	0.766	11.5	16.0	-19.9	43.0	3.14	16.4
186	ZR204 b	0.755	11.4	15.3	-20.1	41.8	3.18	
187	ZR213 a	0.612	11.5	15.3	-20.3	41.9	3.20	3.3
188	ZR213 b	0.520	11.6	15.1	-20.6	42.7	3.29	
189	ZR214 a	0.738	10.9	15.4	-20.5	41.7	3.16	16.4
190	ZR214 b	0.777	10.9	16.3	-20.5	43.8	3.13	
191	ZR240 a	0.636	10.1	15.7	-21.1	43.0	3.19	15.7
192	ZR240 b	0.704	10.1	15.0	-21.0	40.7	3.16	
193	ZR241 a	0.732	11.8	15.9	-19.9	42.5	3.12	15.8
194	ZR241 b	0.516	11.8	15.7	-19.8	42.5	3.16	
195	ZR385 a	0.581	10.6	15.6	-20.5	42.5	3.18	15.7
196	ZR385 b	0.546	10.6	15.7	-20.6	42.5	3.17	
197	ZR444 a	0.528	10.2	15.6	-20.6	42.5	3.17	17.9
198	ZR444 b	0.573	10.2	15.7	-20.5	42.4	3.15	
199	ZR445 a	0.589	9.9	15.6	-20.7	42.4	3.18	15.6
200	ZR445 b	0.533	9.9	15.7	-20.6	42.5	3.16	
201	ZR469 a	0.591	10.7	15.7	-20.6	42.5	3.16	15.4
202	ZR469 b	0.590	10.7	15.6	-20.6	42.8	3.20	
203	ZR505 a	0.534	9.7	15.8	-20.2	42.5	3.14	19.0
204	ZR505 b	0.569	9.7	15.6	-20.3	41.8	3.13	
205	ZR511 a	0.573	12.1	15.7	-19.7	42.4	3.15	14.3
206	ZR511 b	0.601	12.1	15.8	-19.6	42.4	3.13	
207	ZR600 a	0.695	11.5	15.2	-20.4	41.4	3.18	11.0
208	ZR600 b	0.532	11.5	15.1	-20.6	41.6	3.22	
209	ZR600.2a*	0.717	11.3	14.9	-20.6	41.0	3.20	9.2
210	ZR600.2b*	0.617	11.4	14.9	-21.0	42.4	3.31	
211	ZR686 a	0.501	12.0	15.7	-19.9	42.7	3.18	17.5
212	ZR686 b	0.510	11.9	15.7	-19.9	42.4	3.16	
213	ZR698 a	0.561	12.0	15.8	-20.3	42.6	3.15	11.1
214	ZR698 b	0.626	11.9	15.8	-20.3	42.8	3.16	

*Control; 3M-burial pit; K-general cemetery; DA-mass grave 1; ZR-mass grave 2; J-Jelgava comparative population; a, b-duplicate measurements of the same sample

Appendix 3. Supplementary Material S5

Table S5.4. Incremental dentine $\delta^{13}C$ (‰VPDB) and $\delta^{15}N$ (‰AIR) values, % weight, C:N atomic ratios, % collagen yield, types of teeth, and age at death of each individual.

Sample ID	$\delta^{13}C$‰	$\delta^{15}N$ ‰	%C	%N	C:N	%Coll. yield	Tooth	Age in years
GC_12-1	-19.2	13.5	41.5	14.8	3.3	17.3	C'	13-14
GC_12-2	-19.1	12.5	41.1	14.7	3.3			
GC_12-3	-19.1	12.3	41.6	14.8	3.3			
GC_12-4	-18.6	12.9	41.7	15.4	3.2			
GC_12-5	-19.0	12.3	41.9	15.5	3.2			
GC_12-6	-19.6	11.9	41.8	15.4	3.2			
GC_12-7	-19.5	12.3	41.5	15.5	3.1			
GC_12-8	-19.5	12.7	41.6	15.5	3.1			
GC_12-9	-19.5	12.4	41.6	15.4	3.2			
GC_12-10	-19.5	12.9	41.7	15.4	3.1			
GC_12-11	-19.6	12.6	41.4	15.3	3.2			
GC_12-12	-19.8	12.8	41.9	15.4	3.2			
GC_41-1	-20.1	12.4	41.6	14.7	3.3	20.0	C,	14-15
GC_41-2	-19.9	11.5	41.8	14.9	3.3			
GC_41-3	-19.5	13.9	42.2	15.0	3.3			
GC_41-4	-19.4	14.0	41.3	14.9	3.2			
GC_41-5	-19.6	13.8	41.5	14.8	3.3			
GC_41-6	-19.7	11.3	41.7	14.8	3.3			
GC_41-7	-20.0	10.8	41.9	14.9	3.3			
GC_41-8	-20.0	11.3	42.0	14.8	3.3			
GC_41-9	-20.0	11.7	42.0	14.9	3.3			
GC_41-10	-19.9	11.4	41.6	14.8	3.3			
GC_41-11	-19.9	12.4	41.4	14.7	3.3			
GC_41-12	-19.9	12.5	40.3	14.3	3.3			
GC_41-13	-20.2	11.9	41.2	14.4	3.3			
GC_41-14	-20.5	11.3	41.3	14.6	3.3			
GC_63-1	-20.2	14.4	41.2	14.8	3.3	18.5	I1,	7-8
GC_63-2	-20.3	13.2	41.4	14.8	3.3			
GC_63-3	-20.2	12.7	41.9	15.1	3.2			
GC_63-4	-20.2	12.0	41.8	14.9	3.3			
GC_63-5	-20.1	12.2	41.7	15.0	3.2			
GC_63-6	-20.0	12.6	41.4	14.9	3.3			
GC_63-7	-19.9	12.7	41.7	14.8	3.3			
GC_63-8	-19.9	13.0	41.5	14.8	3.3			

GC_85-1	-20.2	12.4	42.0	15.1	3.2	17.7	PM2,	12-13
GC_85-2	-20.6	12.1	41.8	15.0	3.2			
GC_85-3	-20.5	12.2	41.7	14.9	3.3			
GC_85-4	-20.5	12.6	41.7	15.0	3.2			
GC_85-5	-20.3	12.4	41.5	14.9	3.3			
GC_85-6	-20.2	12.4	41.8	14.9	3.3			
GC_85-7	-20.2	12.1	42.1	15.0	3.3			
GC_85-8	-19.9	11.8	41.7	14.8	3.3			
GC_85-9	-19.9	11.6	42.0	15.0	3.3			
GC_134-1	-20.8	11.6	41.7	14.8	3.3	18.8	C'	13-14
GC_134-2	-21.0	10.4	41.6	14.9	3.3			
GC_134-3	-21.2	11.0	41.8	14.9	3.3			
GC_134-4	-21.5	9.7	41.7	14.9	3.3			
GC_134-5	-21.4	10.1	41.5	14.7	3.3			
GC_134-6	-21.3	10.7	42.1	14.9	3.3			
GC_134-7	-20.8	10.3	41.9	14.9	3.3			
GC_134-8	-21.1	10.4	41.7	14.9	3.3			
GC_134-9	-21.1	10.2	42.2	15.0	3.3			
GC_134-10	-20.9	10.3	41.5	14.7	3.3			
GC_134-11	-20.8	10.2	41.6	14.6	3.3			
GC_283-1	-20.3	11.7	42.2	15.0	3.3	21.3	C,	8-9
GC_283-2	-20.0	11.4	41.6	14.7	3.3			
GC_283-3	-20.0	12.1	41.4	14.8	3.3			
GC_283-4	-20.0	12.1	41.7	14.9	3.3			
GC_283-5	-20.0	12.1	41.7	14.9	3.3			
GC_283-6	-20.1	11.6	42.0	14.7	3.3			
GC_283-7	-20.1	11.8	41.8	15.0	3.3			
GC_283-8	-20.2	11.9	41.7	14.8	3.3			
GC_283-9	-20.1	12.2	41.8	14.9	3.3			
GC_283-10	-20.1	12.1	42.0	14.8	3.3			
GC_615-1	-19.4	15.9	41.6	15.0	3.2	15.2	C,	10-11
GC_615-2	-19.7	14.7	41.6	15.0	3.2			
GC_615-3	-19.6	14.1	42.0	15.1	3.2			
GC_615-4	-19.7	13.7	41.8	15.1	3.2			
GC_615-5	-20.0	13.3	41.9	15.0	3.3			
GC_615-6	-20.2	12.8	42.0	15.0	3.3			
GC_615-7	-20.1	12.7	41.7	15.0	3.2			
GC_615-8	-19.9	12.8	42.0	15.0	3.3			
GC_615-9	-19.9	12.0	42.2	15.1	3.3			
GC_615-10	-19.8	11.9	41.6	14.9	3.3			
GC_615-11	-20.0	11.2	41.8	14.8	3.3			

GC_615-12	-20.0	11.2	47.0	16.8	3.3			
GC_615-13	-20.0	11.2	41.5	14.8	3.3			
MG1_83-1	-21.2	12.0	41.2	14.7	3.3	15.1	C'	10-11
MG1_83-2	-20.9	11.5	41.3	14.8	3.2			
MG1_83-3	-21.0	11.3	41.5	14.8	3.3			
MG1_83-4	-20.8	11.1	41.4	14.9	3.2			
MG1_83-5	-20.4	11.8	41.8	15.0	3.2			
MG1_83-6	-20.1	12.0	41.2	14.8	3.3			
MG1_83-7	-19.9	11.5	42.6	15.2	3.3			
MG1_83-8	-19.8	11.5	41.4	14.8	3.3			
MG1_83-9	-19.8	12.2	40.6	14.5	3.3			
MG1_127-1	-19.1	12.9	42.1	15.0	3.3	21.7	C'	11-13
MG1_127-2	-19.1	12.7	41.5	14.8	3.3			
MG1_127-3	-19.2	12.6	42.0	15.0	3.3			
MG1_127-4	-19.1	12.6	41.9	15.0	3.3			
MG1_127-5	-19.1	12.2	42.1	15.0	3.3			
MG1_127-6	-19.2	12.2	42.0	14.9	3.3			
MG1_127-7	-19.4	12.5	41.7	14.9	3.3			
MG1_127-8	-19.5	12.3	42.4	15.0	3.3			
MG1_127-9	-19.5	11.6	41.9	14.8	3.3			
MG1_127-10	-18.9	12.4	41.6	14.7	3.3			
MG1_127-11	-18.9	12.8	41.4	14.9	3.2			
MG1_156-1	-21.0	10.5	41.4	14.8	3.3	19.9	C'	9-11
MG1_156-2	-20.9	10.1	38.5	13.7	3.3			
MG1_156-3	-20.6	9.2	41.0	14.6	3.3			
MG1_156-4	-20.9	9.9	41.2	14.7	3.3			
MG1_156-5	-21.1	10.1	41.6	14.9	3.3			
MG1_156-6	-21.0	10.1	41.5	14.8	3.3			
MG1_156-7	-20.8	9.9	41.5	14.9	3.3			
MG1_156-8	-20.5	9.7	41.3	14.7	3.3			
MG1_156-9	-20.5	9.9	41.8	14.9	3.3			
MG1_156-10	-20.5	10.4	41.4	14.8	3.3			
MG1_156-11	-20.2	11.5	41.3	14.6	3.3			
MG1_497-1	-19.7	14.3	41.3	14.7	3.3	18.9	C'	13-14
MG1_497-2	-20.1	12.2	40.4	14.3	3.3			
MG1_497-3	-20.0	12.1	41.1	14.6	3.3			
MG1_497-4	-20.0	12.3	41.1	14.6	3.3			
MG1_497-5	-19.8	12.3	40.9	14.5	3.3			
MG1_497-6	-19.9	11.8	41.3	14.6	3.3			
MG1_497-7	-19.9	11.7	40.4	14.4	3.3			

MG1_497-8	-19.8	11.9	41.2	14.6	3.3			
MG1_497-9	-19.7	11.7	40.4	14.2	3.3			
MG1_497-10	-19.7	11.8	41.0	14.5	3.3			
MG1_497-11	-19.9	11.3	41.2	14.6	3.3			
MG1_497-12	-20.1	11.6	41.2	14.5	3.3			
MG1_497-13	-20.0	11.7	41.0	14.5	3.3			
MG1_497-14	-20.0	11.7	40.6	14.4	3.3			
MG1_497-15	-20.2	11.0	41.2	14.6	3.3			
MG1_497-16	-19.7	12.6	40.8	14.3	3.3			
MG1_627-1	-20.2	13.5	41.6	15.2	3.2	18.2	C,	10-11
MG1_627-2	-20.4	13.0	41.7	15.3	3.2			
MG1_627-3	-20.3	12.8	41.6	15.3	3.2			
MG1_627-4	-20.2	12.3	42.2	15.5	3.2			
MG1_627-5	-20.2	12.0	41.9	15.5	3.2			
MG1_627-6	-19.9	12.3	41.5	15.2	3.2			
MG1_627-7	-20.1	12.4	41.8	15.4	3.2			
MG1_627-8	-20.1	12.1	42.1	15.5	3.2			
MG1_627-9	-19.6	11.4	43.7	15.6	3.3			
MG1_627-10	-20.0	12.3	41.6	15.3	3.2			
MG1_627-11	-19.8	12.4	41.9	15.4	3.2			
MG1_627-12	-19.5	12.3	41.9	15.5	3.2			
MG1_627-13	-19.3	12.2	42.5	15.6	3.2			
MG1_627-14	-19.2	13.0	41.6	15.3	3.2			
MG1_630-1	-19.8	15.1	41.1	14.6	3.3	19.0	C,	11-12
MG1_630-2	-20.5	12.9	41.3	14.7	3.3			
MG1_630-3	-20.9	11.5	41.6	14.8	3.3			
MG1_630-4	-20.5	11.7	41.4	14.9	3.2			
MG1_630-5	-20.5	11.5	41.4	15.0	3.2			
MG1_630-6	-20.2	12.3	41.4	15.0	3.2			
MG1_630-7	-20.3	12.1	41.3	14.9	3.2			
MG1_630-8	-20.2	12.0	41.2	14.9	3.2			
MG1_630-9	-20.3	11.8	41.7	15.1	3.2			
MG1_630-10	-20.2	11.9	41.5	15.0	3.2			
MG1_630-11	-20.1	12.0	41.5	15.0	3.2			
MG1_630-12	-19.9	11.8	41.4	14.9	3.2			
MG1_630-13	-19.9	11.7	40.6	14.6	3.2			
MG1_630-14	-19.8	12.0	42.0	14.9	3.3			
MG1_630-15	-19.7	12.1	41.8	14.9	3.3			
MG1_630-16	-19.7	12.9	42.1	15.0	3.3			
MG2_103-1	-19.5	16.0	41.5	15.3	3.2	20.1	C'	10-11
MG2_103-2	-19.7	14.4	41.8	15.5	3.2			

MG2_103-3	-20.4	11.8	41.3	15.3	3.2			
MG2_103-4	-20.5	11.6	41.9	15.5	3.2			
MG2_103-5	-20.3	12.0	41.6	15.3	3.2			
MG2_103-6	-20.1	12.0	42.0	15.6	3.1			
MG2_103-7	-20.1	11.8	42.1	15.6	3.2			
MG2_103-8	-20.0	11.7	42.1	15.4	3.2			
MG2_103-9	-20.1	11.4	42.1	15.6	3.1			
MG2_103-10	-19.7	11.2	42.4	15.6	3.2			
MG2_103-11	-19.6	11.7	42.5	15.6	3.2			
MG2_103-12	-19.5	11.5	42.0	15.6	3.1			
MG2_103-13	-19.7	12.2	42.0	15.6	3.2			
MG2_177-1	-19.5	13.3	41.0	14.7	3.3	18.1	C'	10-11
MG2_177-2	-19.5	12.6	41.3	14.8	3.3			
MG2_177-3	-19.5	12.5	41.2	14.8	3.2			
MG2_177-4	-19.5	12.7	41.3	14.9	3.2			
MG2_177-5	-19.3	12.8	41.2	14.8	3.3			
MG2_177-6	-19.4	12.5	41.1	14.7	3.3			
MG2_177-7	-19.6	12.4	41.2	14.9	3.2			
MG2_177-8	-19.6	12.2	41.0	14.6	3.3			
MG2_177-9	-19.6	11.9	40.7	14.6	3.3			
MG2_177-10	-19.5	12.1	40.9	14.7	3.2			
MG2_177-11	-19.4	12.2	41.2	14.7	3.3			
MG2_177-12	-19.3	12.1	41.1	14.7	3.3			
MG2_177-13	-19.3	12.2	41.2	14.7	3.3			
MG2_177-14	-19.2	12.5	41.2	14.6	3.3			
MG2_432-1	-19.1	12.8	46.2	16.8	3.2	20.3	C'	10-11
MG2_432-2	-19.4	12.4	41.5	15.0	3.2			
MG2_432-3	-19.6	11.7	41.6	15.1	3.2			
MG2_432-4	-19.6	10.9	41.8	15.0	3.2			
MG2_432-5	-19.5	11.5	41.7	15.1	3.2			
MG2_432-6	-19.5	11.8	41.6	15.0	3.2			
MG2_432-7	-19.3	12.7	41.5	14.9	3.2			
MG2_432-8	-19.4	12.8	41.4	14.9	3.2			
MG2_432-9	-19.4	12.9	41.6	14.9	3.2			
MG2_432-10	-19.4	12.8	41.7	14.9	3.3			
MG2_508-1	-19.2	15.0	41.1	14.8	3.2	16.9	C,	8-9
MG2_508-2	-19.6	13.6	41.3	15.0	3.2			
MG2_508-3	-19.5	13.1	41.8	15.2	3.2			
MG2_508-4	-19.3	13.1	41.6	15.0	3.2			
MG2_508-5	-19.0	12.8	41.3	15.0	3.2			
MG2_508-6	-18.8	13.4	41.5	15.0	3.2			

MG2_508-7	-18.9	13.2	41.5	15.1	3.2			
MG2_516-1	-20.9	11.2	41.8	15.3	3.2	18.2	C,	10-11
MG2_516-2	-20.8	10.2	41.5	15.4	3.1			
MG2_516-3	-20.9	10.7	41.6	15.4	3.2			
MG2_516-4	-20.7	10.8	41.9	15.4	3.2			
MG2_516-5	-20.8	10.7	42.1	15.6	3.1			
MG2_516-6	-20.8	11.2	41.8	15.4	3.2			
MG2_516-7	-20.5	11.3	42.3	15.5	3.2			
MG2_516-8	-20.4	11.4	42.0	15.4	3.2			
MG2_516-9	-20.3	11.6	41.7	15.2	3.2			
MG2_516-10	-20.1	11.6	42.0	15.4	3.2			
MG2_516-11	-19.9	11.2	42.3	15.5	3.2			
MG2_516-12	-19.6	11.4	41.6	15.1	3.2			
MG2_516-13	-19.7	10.9	41.7	15.1	3.2			
MG2_606-1	-20.8	11.1	40.5	14.4	3.3	20.4	C,	10-11
MG2_606-2	-20.9	11.1	41.5	14.1	3.4			
MG2_606-3	-20.7	10.9	40.9	14.5	3.3			
MG2_606-4	-20.6	10.6	41.0	14.6	3.3			
MG2_606-5	-20.6	10.6	41.1	14.6	3.3			
MG2_606-6	-20.5	10.4	41.1	14.5	3.3			
MG2_606-7	-20.4	10.7	43.9	15.7	3.3			
MG2_606-8	-20.9	10.3	42.1	14.4	3.4			
MG2_606-9	-20.3	10.3	41.1	14.6	3.3			
MG2_606-10	-19.7	11.4	41.0	14.6	3.3			
MG2_606-11	-19.6	11.4	41.2	14.7	3.3			
MG2_606-12	-19.6	11.5	40.5	14.3	3.3			
MG2_606-13	-19.6	10.8	41.0	14.6	3.3			
MG2_606-14	-19.9	11.2	41.0	14.6	3.3			

Notes: C’-upper canine; C,-lower canine; I1,-lower first incisor; PM2,-lower second premolar.

Appendix 4. Supplementary Material S6

Table S6.5. Cribra orbitalia and maxillary sinusitis in adults and children by affected/observed individuals and orbits and sinuses (including bones only of one side)

Context	Cribra orbitalia					
	By individual			By orbit count		
	Males	Females	Children	Males	Females	Children
GC	12/46	3/36	34/93	19/90	6/71	64/163
MGs	15/87	8/62	33/67	26/170	15/121	63/128
	Maxillary sinusitis					
	By individual			By sinus count		
	Males	Females	Children	Males	Females	Children
GC	3/23	3/12	0/46	4/41	6/22	0/91
MGs	14/42	6/17	0/36	19/53	11/34	0/71

Table S6.6. LEH in adults by affected/observed individuals and teeth

By individual				
	Males		Females	
	GC	MGs	GC	MGs
LEH	34/44	63/87	27/40	42/54
LEH2	18/34	32/63	9/27	20/42
By tooth count				
LEH	198/858	321/1786	160/678	284/1072
LEH2	94/198	93/321	40/160	84/284

Table S6.7. Bilateral periosteal reactions, and periodontal disease in adult individuals

	Bilateral PR on legs, and PD		Observed individuals		%	%
	GC	MGs	GC	MGs	GC	MGs
Males	3	15	22	72	13.6	20.8
Females	5	6	27	41	18.5	14.6
Total	8	21	49	113	16.3	18.6

PR-periosteal reactions; PD-periodontal disease

Table S6.8. Distribution of woven new bone in all individuals with periosteal reactions on the long bones of arms and/or legs

	By affected individual count					
	Females			Males		
	NWB	PR	%	NWB	PR	%
GC	4	33	**12.1**	6	28	**21.4**
MGs	2	26	**7.7**	2	55	**3.6**
	By affected long bone count					
GC	12	83	**14.5**	14	77	**18.2**
MGs	2	69	**2.9**	6	156	**3.8**

NWB-new woven bone; PR-periosteal reactions

Table S6.9. Periosteal reactions on adult long bones by affected/observed individuals and bones by age group

By individual count								
Young Females				Older females				
	Femur	Tibia	Fibula	Ulna	Radius	Femur	Tibia	Fibula
GC	4/19	10/16	2/16	0/44	1/41	5/42	15/38	3/36
MGs	8/25	10/20	2/16	0/34	0/39	2/39	11/38	2/27
Young Males				Older males				
GC	4/23	8/22	3/19	2/48	1/49	5/46	17/39	8/37
MGs	13/29	15/29	4/23	1/56	1/58	18/62	30/57	8/48
By long bone count								
	Femur	Tibia	Fibula	Ulna	Radius	Femur	Tibia	Fibula
Young Females				Older females				
GC	8/37	18/32	2/32	0/72	1/70	8/74	24/72	4/67
MGs	14/49	19/38	3/31	0/67	0/72	4/77	19/70	4/50
Young males				Older males				
GC	8/39	16/36	4/31	2/79	1/72	7/78	26/71	10/63
MGs	24/57	26/57	5/45	1/111	1/115	33/122	56/113	11/93

Table S6.10. Bilateral periosteal reactions on adult long bones by affected/observed individuals and bones

	Context	**By individual**			**By bone count**		
		Femur	Tibia	Fibula	Femur	Tibia	Fibula
Females	GC	7/56	23/69	2/63	14/112	46/138	4/126
	MGs	8/59	19/50	4/35	16/118	38/100	8/70
Males	GC	6/53	16/55	3/45	12/106	32/110	6/90
	MGs	26/87	38/83	4/63	52/174	76/166	8/126

Table S6.11. Residual rickets in adults by affected/observed bones

	By long bone count										
	Context	Radius	%	Ulna	%	Femur	%	Tibia	%	Fibula	%
Females	GC	2/107	1.9	2/110	1.8	6/126	4.8	7/143	4.9	3/133	2.3
	MGs	0/113	0.0	0/115	0.0	5/126	4.0	9/108	8.3	0/81	0.0
Males	GC	4/113	3.5	5/119	4.2	8/133	6.0	10/130	7.7	4/113	3.5
	MGs	0/169	0.0	0/170	0.0	18/179	10.1	19/170	11.2	5/138	3.6

Table S6.12. LEH in children by affected/observed individuals and teeth

By individual						
	Deciduous/total		Permanent/total		Total	
	GC	MGs	GC	MGs	GC	MGs
LEH	6/95	1/66	28/95	43/66	34/95	43/66
LEH 2	0/6	0/1	16/28	24/43	16/34	24/43
By tooth						
LEH	11/735	3/321	178/375	339/930	189/1110	342/1251
LEH 2	0/11	0/3	83/178	115/339	83/189	115/342

Table S6.13. Scurvy and rickets in the affected children, by affected/observed skeletal elements

	By individual		By bone count	
	Scurvy	Rickets	Scurvy	Rickets
Orbits*	5/7	5/5	10/14	10/10
St. ends	0/5	0/2	0/34	0/16
Frontal bones	2/7	1/6	3/14	2/10
Parietal bones	0/3	1/2	0/5	1/2
Occipital bone	2/5	1/1	2/5	1/1
IFOF	5/7	N/A	8/12	N/A
AR	2/6		4/11	
GWS	6/6		7/7	
SSPF	7/7		11/13	
ISPF	2/8		3/13	
Humeri	2/6	0/7	4/11	0/13
Radii	0/6	1/5	0/9	2/9
Ulnae	0/6	0/6	0/10	0/11
Femora	1/6	4/7	2/11	6/13
Tibiae	5/6	3/7	10/11	4/12
Fibulae	0/6	2/5	0/8	3/7

St. ends – sternal ends of ribs; IFOF-infra-orbital foramen of the maxilla; AR-ascending ramus of the mandible; GWS-greater wing of sphenoid; SSPF-supra-spinous fossa of the scapula; ISPF-infra-spinous fossa of the scapula.

Table S6.14. Non-specific pathological changes in children, by affected/observed individuals and bones

	By individual		By bone count	
	GC	MGs	GC	MGs
Orbits*	12/93	2/67	20/163	3/128
Frontal bones	9/92	2/94	16/163	4/125
Parietal bones	1/33	0/43	2/58	0/83
Occipital bone	2/38	0/44	2/38	0/44
IFOF	6/65	0/62	12/116	0/116
AR	6/98	1/69	11/173	1/130
GWS	4/43	2/47	7/62	3/85
SSPF	10/115	4/56	17/182	6/92
ISPF	1/114	0/57	1/181	0/93
Humerus^	1/54	0/19	1/54	0/19
Humeri^^	2/80	0/59	4/160	0/118
Radius^	0/58	0/17	0/58	0/17
Radii^^	1/60	0/54	2/120	0/108
Ulna^	1/47	0/16	1/47	0/16
Ulnae^^	1/74	0/54	2/148	0/108
Femur ^	4/25	0/7	4/25	0/7
Femora^^	2/96	0/66	4/96	0/132
Tibia^	1/20	0/15	1/20	0/15
Tibiae^^	8/92	4/53	16/184	8/106
Fibula^	0/29	1/18	0/29	1/18
Fibulae^^	2/66	1/34	4/132	2/68

*-new bone formation; ^- bone of one side affected/observable; ^^bones from both sides affected/observable; St. ends – sternal ends of ribs; IFOF-infra-orbital foramen of the maxilla; AR-ascending ramus of the mandible; GWS-greater wing of sphenoid; SSPF-supra-spinous fossa of the scapula; ISPF-infra-spinous fossa of the scapula.

Table S6.15. Observable individuals and skeletal elements for palaeopathological analysis

	By individual						By skeletal element					
	Non-adults		Males		Females		Non-adults		Males		Females	
	GC	MGs	GC	MGs	GC	MGs	GC	MGs	GC	MGs	GC	MGs
Orbits*	93	67	46	87	36	62	163	128	90	170	71	121
Max. sinuses	51	40	23	42	12	17	91	71	41	53	22	34
Ind. ribs	57	26	44	53	43	31	322	76	216	166	126	81
St. ends	51	20	41	50	38	28	227	44	122	144	108	61
Frontal bones	92	64	42	78	37	59	164	125	84	152	73	118
Parietal bones	33	43	42	65	33	52	58	83	84	129	66	104
Occipital bone	38	44	41	63	30	50	38	44	41	63	30	50
IFOF	65	62	N/A				116	116	N/A			
AR	98	69					173	130				
GWS	43	47					62	85				
SSPF	115	56					182	92				
ISPF	114	57					181	93				
Individuals with both left and right long bones observable												
Humeri	80	59	41	74	35	50	160	118	82	122	70	100
Radii	60	54	39	78	43	51	120	108	78	156	86	102
Ulnae	74	54	46	78	42	52	148	108	92	156	84	104
Femora	96	66	53	87	56	59	192	132	106	174	112	118
Tibiae	92	53	55	83	69	50	184	106	110	166	138	100
Fibulae	66	34	45	63	63	35	132	68	90	126	126	70
Total observable individuals and long bones												
Humeri	133	78	69	94	59	64	214	137	110	168	94	114
Radii	118	71	74	91	64	62	178	125	113	169	107	113
Ulnae	121	70	73	92	68	63	195	124	119	170	110	115
Femora	121	73	80	92	70	67	217	139	133	179	126	126
Tibiae	112	68	75	87	74	58	204	121	130	170	143	108
Fibulae	95	52	68	75	70	46	161	86	113	138	133	81

Notes: *-including elements only from one side; Ind. – individual; St. ends – sternal ends of ribs; IFOF-infra-orbital foramen of the maxilla; AR-ascending ramus of the mandible; GWS-greater wing of sphenoid; SSPF-supra-spinous fossa of the scapula; ISPF-infra-spinous fossa of the scapula.

Appendix 5. Supplementary Material S7

Table S7.8. Prevalence of caries and LEH, using different methods

		Caries n/N	%	LEH n/N (1)	%	LEH n/N (2)	%
SGCC_GC	Males	26/41	63.4	34/44	77.3	25/30	83.3
	Females	9/28	32.1	27/34	79.4	16/20	80.0
SGCC_MGs	Males	41/72	56.9	63/87	72.4	27/35	77.1
	Females	29/49	59.2	42/54	77.8	19/23	82.6

n-affected individuals; N-observed individuals; (1)-only individuals with at least one canine included in the analysis; (2)-only individuals with at least one upper incisor, and one lower canine, included in the analysis; SGCC-St Gertrude Church cemetery; GC-general cemetery; MGs-mass graves

Table S7.9. Results of statistical testing for different methods of caries and LEH prevalence calculations in the St Gertrude's cemetery population, against the original results

		N	χ^2	df	p value
Methods test: Caries					
GC	Males	85	0	1	1
	Females	68	0.16	2	0.689
MGs	Males	159	0.25	1	0.617
	Females	103	0	1	1
Methods test: LEH (2)					
GC	Males	74	0.12	1	0.729
	Females	60	0.5	1	0.479
MGs	Males	122	0.1	1	0.752
	Females	77	0.03	1	0.862

N-number of individuals; χ^2=chi square value; df-degrees of freedom; GC-general cemetery; MGs – mass graves; (2)-only individuals with at least one upper incisor, and one lower canine, included in the analysis

Table S7.10. Results of chi-square tests for different prevalence rates of dental disease, cribra orbitalia, LEH; and unpaired t-tests for differences in adult stature

Group	Population	Statistics	P value
	Caries (chi-square test)		
Males	GC, Cesvaine	N=58, χ^2=3.37, df=1	p=0.066
	GC, VSSCC, JHTCC	N=75, χ^2= 5.33, df=2	p=0.070
	MGs, Cesvaine, Madona, Tääksi	N=130, χ^2=5.6, df=3	p=0.133
	MGs, VSSCC	N=98, χ^2= 1.46, df=1	p=0.227
Females	GC, Ventspils, PSJCC	N=78, χ^2=3.32, df=2	p=0.190
	GC, Madona	N=49, χ^2= 2.83, df=1	p=0.092
	GC, Tääksi	N=61, χ^2= 4.26, df=1	p=0.039*
	GC, JHTCC	N=65, χ^2= 6.64, df=1	p=0.01*
	GC, VSSCC	N=52, χ^2= 3.24, df=1	p=0.072
	MGs, Madona, Cesvaine, Tääksi	N=103, χ^2= 4.96, df=3	p=0.175
	MGs, VSSCC, JHTCC	N=91, χ^2= 3.22, df=2	p=0.200

	Periapical lesions		
Males	GC, MGs, JHTCC, Madona, Cesvaine	N=181, χ^2=5.43, df=4	p=0.246
Females	GC, MGs, Madona, Ventspils	N=121, χ^2=3.6, df=3	p=0.308
	AMTL		
Females	GC, MGs, VSSCC	N=105, χ^2= 2.63, df=2	p=0.268
	GC, MGs, JHTCC	N=121, χ^2=5.25, df=2	p=0.072
	LEH		
Adults	GC, MGs, Subačius str.	N=474, χ^2=70.66, df=2	p<0.001*
Children	GC, JHTCC	N=114, χ^2=5.92, df=1	p=0.015*
	MGs, GC	N=161, χ^2= 18.69, df=1	p<0.001*
	MGs, JHTCC	N=85, χ^2= 22.51, df=1	p<0.001*
	MGs, Old Panevėžys	N=92, χ^2= 16.55, df=1	p<0.001*
	CO		
Males	GC, RDSC	N=184, χ^2=11.78, df=1	p=0.001*
	GC, Alytus	N=364, χ^2=9.88, df=1	p=0.002*
	GC, VSSCC	N=61, χ^2=3.76, df=1	p=0.052
	GC, JHTCC	N=81, χ^2=0.04, df=1	p=0.841
	GC, Madona, Cesvaine	N=85, χ^2=3.96, df=2	p=0.138
	MGs, RDSC	N=225, χ^2=5.6, df=1	p=0.018*
	MGs, Alytus	N=405, χ^2=3.65, df=1	p=0.056
	MGs, Madona, VSSCC	N=115, χ^2=5.82, df=2	p=0.054
Females	GC, MGs, Madona, VSSCC	N=126, χ^2=4.83, df=3	p=0.185
	GC, Old Panevėžys	N=91, χ^2= 8.51, df=1	p=0.003*
	MGs, Old Panevėžys	N=117, χ^2= 8.68, df=1	p=0.003*
Children	GC, JHTCC	N=99, χ^2= 1.07, df=1	p=0.301
	GC, Alytus	N=454, χ^2= 8.37, df=1	p=0.004
	MGs, Alytus	N=433, χ^2= 19.45, df=	p<0.001*
	MGs, RDSC	N=133, χ^2= 8.07, df=1	p=0.004*
	MGs, JHTCC, VSSCC	N=92, χ^2= 5.74, df=2	p=0.057
	Adult stature (t-test)		
Males	GC, MGs	t=1.16	p=0.247
	GC, Ventspils	t=1.43	p=0.156
	GC, Saldus General	t=1.06	p=0.292
	GC, Priedīši	t=1.20	p=0.231
	GC, Saldus Church	t=1.58	p=0.116
	GC, RDCC	t=1.21	p=0.228
	GC, JHTCC	t=2.51	p=0.013*
	MGs, Ventspils	t=2.20	p=0.029*
	MGs, JHTCC	t=3.33	p=0.001*
	MGs, Saldus Church	t=2.19	p=0.031*
	MGs, RDCC	t=1.93	p=0.057
Females	GC, Priedīši	t=1.84	p=0.068
	MGs, Ventspils	t=1.70	p=0.092
	MGs, Priedīši	t=1.20	p=0.232
	MGs, RDCC	t=1.68	p=0.095
	MGs, JHTCC	t=1.55	p=0.123
	MGs, Saldus Church	t=0.96	p=0.341

LEH-linear enamel hypoplasia; CO-cribra orbitalia; N=number of individuals; χ^2-chi square value, df-degrees of freedom

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